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39DIDSOLIT-PB: Development and implementation of decentralised solar-energy-related innovative technologies for public buildings, in the Mediterranean Basin countries.

Coordinator Institution: BEG-INCERS Research Group – **Universitat Autònoma de Barcelona (UAB)**

REPORT 5

Comparative costs analysis for the selected innovative solar technologies

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CONTENT

INTRODUCTION

In this report we present the results of our cost study –based on market prices forecast- for the finally selected innovative technologies to be applied in public buildings by Project's Partners; this study is therefore the outcome from activity 4.3 of Project's WP 4.

Two of the selected technologies are of the Concentration Solar Power (CSP) type,

- Thermoelectric Dish Stirling design
- Solar cooling absorption system with Parabolic Trough as solar- field design

and three of them are of the non-standard, thin-layer, building-integrated-photovoltaic (BIPV) type,

- BIPV (1) = Crystalline PV, glass-like modules. (30% - 40% transparency)
- BIPV (2) = Thin film (a-S)i semitransparent (10-20%) sheets (EFTE)
- BIPV (3) = Flexible thin film

Thus, the main objective of this study is to elaborate an up-dated forecast for costs and yield of each of these technologies, for in-building applications, taking into account the prevailing climate conditions in the partners' regions.

To sum up, for each of the referred technologies we evaluate or forecast investment costs, maintenance costs, yield, and finally the corresponding estimate for the cost per kWh. Additionally for all those variables we take as an external comparative reference up-dated costs & yield data for the more mature technology 'PV-standard' chrystalline modules.

The paper is organised in four sections. Section 1 is devoted to a costs analysis of DS and PT technologies for electricity generation. It starts by an overview of the state of the topic according to international literature[1]; and then it follows an estimate of the economic variables for scale-down systems the Project is focused on; that is, forecast of detailed costs and yields are estimated, for

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[1] This overview is drawn from our working document *"Comparative costs analysis of Dish Stirling and Parabolic Trough"*.

applications to be carried out in public buildings, placed in Mediterranean regions [2]. That point on forecast for CSP systems does not cover scale-down models of PT for electricity generation because that option has finally been discarded within the project –as a result of the first work-package 4 studies (see Report 2).

Section 2 is devoted to the comparative costs of the well known solar-cooling technology but from the specific outlook of using a PT unit as sun-radiation collector –according to the objectives of the Project. Here, again, attention is first driven to the state of the topic (technical alterinatives, costs and yields) according to international literature [3]; and then it is presented a forecast on the costs and economic variables for the specific combined SCH-PT system designed as a result of work-package 4 activities [4].

Section 3 is devoted to the forecast and comparative unit-costs of the three BIPV technologies above referred. It starts by a summary of the state of the topic –regarding economic data- according to available literature; the approach here being a market-data exploratory study [5]. Then a comparative cost-per-kWh forecast for each of the referred three technologies –for applications in the Mediterranean regions- is presented [6]. For comparative purpose, it is also included here the parallel data for the more mature standard-PV modules: costs (investment, and maintenance), yield, and therefore, cost per kWh.

Finally, in section 4 an account of the overall conclusions on this first approach to comparative costs arisen from previous sections is presented.

(The more detailed internal/working documents referred to here in the foot-notes might be made available under request)

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[2] That forecast is mainly based on a) Project’s internal document T 4.2.3.1 DS (”Viability Study” for scaled-down DS systems; section ‘Economic data’), b) our market’s exploratory study (internal working document T4.3.2.2.DS), and c) actual costs and yield data gathered from our carrying out a DS pilot system (working document T4 2.3.3. Prototype DS).

[3] This summary of the state of the topic is drawn from our more comprehensive working document *“Solar cooling systems. A comparative and technological review”*

[4] That forecast is mainly based on a) Project’s internal document T 4.2.3.1 SCH (”Viability Study” for a solar-cooling system fed by a PT unit; its section on ‘Economic data’), b) our market’s exploratory study (our internal working document T4.3.2.2.SCH.

[5] This overview is drawn from our working document *“Solar photovoltaic costs analysis”, Part I.*

[6] That forecast is mainly based on a) our working document *“Solar photovoltaic costs analysis”, Part II*; and b) internal document T 4.3.2.5 BIPV (market’s exploratory study).

1 COSTS STUDY FOR *DISH STIRLING* (DS) AND *PARABOLIC TROUGH* (PT) TECHNOLOGIES

1.1 An overview of available economic studies on decentralised CSP, at international level

1.1.1. CSP Technologies: Terminology and elements

Concentrated Solar Power (CSP) refer to various thermoelectric systems that use mirrors or lenses with tracking systems to concentrate large area of sunlight onto a small area to generate heat and eventually electricity from concentrated sunlight heat.

Based on the electrical generation capacity, CSP technologies can be divided into four groups, defined as large-scale everything over 1 MW, medium-scale everything under 1 MW, small-scale everything under 500 kW and, finally, micro-scale everything under 20 kW [5].

Concentrated Solar Power (CSP) technologies can be divided into two groups, based on whether the solar collectors concentrate the sun rays along a focal line or on a single focal point [2][3][4][6]:

- **Line-focusing systems** track the sun along a single axis and focus irradiance on a linear receiver, which makes tracking simpler. Line systems concentrate radiation about 100 times, and achieve working temperatures of up to 550°C. Parabolic Trough (PT) and Linear Fresnel Reflector (LFR) systems are line-focusing systems.
- **Point-focusing systems** track the sun along two axes and focus irradiance at a single point receiver, which allows higher temperatures. Point systems can concentrate far more than 1,000 times and achieve working temperatures of more than 1,000°C.The following systems, Solar Dish (SD), may be referred as Dish Stirling or Parabolic Dish, and Solar Tower (ST), may be referred as Central Receiver, are point-focusing systems.

Moreover, the solar receiver can be divided into two types, based on whether the receiver is fixed or mobile [2][3][4][5][6]:

- **Fixed receivers** are stationary devices that remain independent of the plant's focusing device. This eases the transport of collected heat to the power block.
- **Mobile receivers** move together with the focusing device. In both line focus and point focus designs, mobile receivers collect more energy.

So, there are four main CSP technology families, which can be categorized by the way they focus the sun rays and the technology used to receive the sun energy. Four main elements are required: a concentrator, a receiver, some form of transport media or storage, and power conversion. The Fossil-fired Back-up system is an alternative component of CSP plants [2][4][6].

In Figure 1, the scheme of concentrating solar collector and concentrating solar thermal power plant is presented.

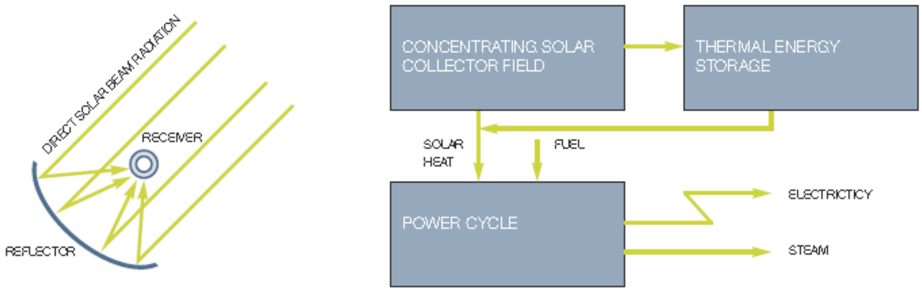

Figure 1 Scheme of concentrating solar collector and CSP plant. Source: [4]

- **Parabolic Trough**

Parabolic trough-shaped mirror reflectors are used to concentrate sunlight on to thermally efficient receiver tubes, which may be fixed or mobile, placed in the trough's focal line. The troughs are usually designed to track the Sun along one axis, predominantly north–south. A heat-transfer medium that circulates inside the receiver absorbs the highly concentrated radiation reflected by the parabolic trough-shaped mirrors and converts it into thermal energy. The heat-transfer medium is then used to generate electricity in a steam Rankine cycle turbine, an organic Rankine cycle turbine or a Stirling engine. To date, the heat transfer media demonstrated include water/steam, mineral and synthetic oils and molten salts. It is possible the Hybrid operation and the thermal storage [2][3][4].

- **Solar Tower or Central Receiver**

A circular array of heliostats (mirrors with sun tracking motion) concentrates sunlight on to a fixed central receiver mounted on the top of a tower. A heat-transfer medium in this central receiver absorbs the highly concentrated radiation reflected by the heliostats and converts it into thermal energy. The heat-transfer medium is then used to generate electricity in a steam Rankine cycle turbine, a gas turbine or a gas and steam combined cycles. To date, the heat transfer media demonstrated include water/steam, molten salts and air. It is possible the Hybrid operation and the thermal storage [2][3][4].

- **Dish Stirling, Solar Dish or Parabolic Dish**

A parabolic dish-shaped reflector concentrates sunlight on to a mobile receiver located at the focal point of the dish. The mirrors are usually designed to track the Sun along two axes. The concentrated beam radiation is absorbed into the receiver to heat a fluid or gas (air) which is then used to generate electricity in a small piston or Stirling engine or a micro turbine, attached to the receiver. The Hybrid operation and thermal storage are under research and development. [2][3][4].

- **Fresnel Linear Reflector**

An array of nearly-flat reflectors concentrates solar radiation onto elevated inverted linear receivers. The mirrors are usually designed to track the sun along one axis, predominantly north–south. A heat-transfer medium that circulates inside the receiver absorbs the concentrated radiation reflected by the mirrors and converts it into thermal energy. The heat-transfer medium is then used to generate electricity in a steam Rankine cycle turbine. To date, the heat transfer media demonstrated is water/ It is possible the Hybrid operation and the thermal storage [2][3][4]. This system is similar to Parabolic Trough.

In Figure 2 the four main Concentrated Solar Power technologies families are presented.

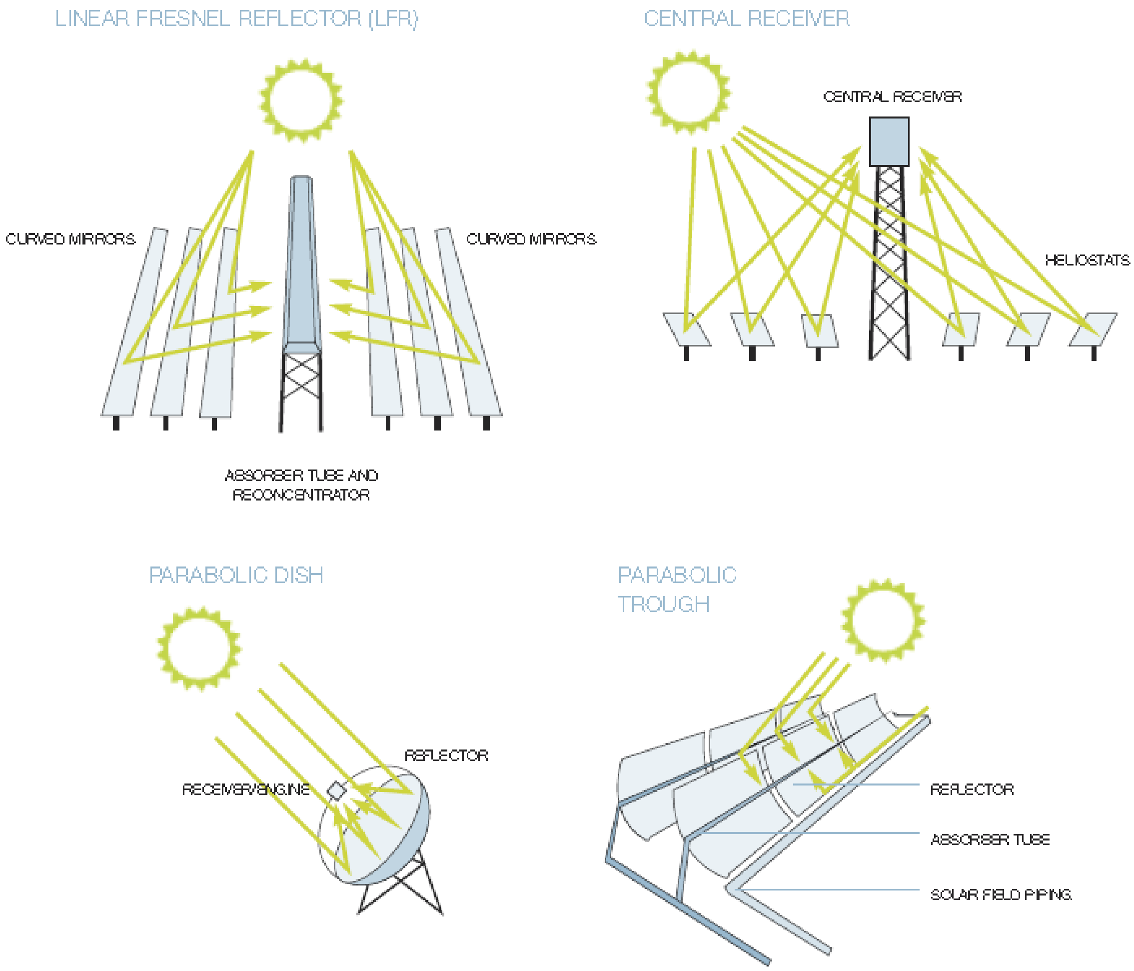

Figure 2 Concentrated Solar Power technology families. Source: [4]

A **Parabolic Trough** system (shown in figure 1) employs parabolic shaped mirrors to concentrate the solar radiation onto a tubular receiver. As a result of this cross-section, sunlight reflected within the trough is focused along a line running the length of the trough. In order to collect this heat, a pipe is positioned along the length of the trough at its focus and a heat collection fluid is pumped through it. The tube (or receiver) is designed to be able to absorb most of the energy focused onto it and must be able to withstand the resultant high temperature (Poullikkas, 2009).

The **Dish Stirling** systems (shown in figure 2) use mirrored dishes to focus and concentrate sunlight onto a solar receiver located at the focal point of the dish. A receiver is designed to transfer the absorbed solar energy to the working fluid in Stirling engine. This engine then converts the absorbed thermal energy to a mechanical power by compressing the working fluid when it is cool and expanding it when it is hot. The linear motion is converted to a rotary motion to turn a generator to produce electricity. To increase the efficiency of these systems; they must be equipped with a dual tracking solar mechanism that keeps the dish aperture always normal to the incoming solar radiation.

Stirling dish systems have demonstrated the highest efficiency of any solar power generation system by converting nearly 31.25% of direct normal incident solar radiation into electricity (Taggart, 2008).

These systems have been tested mainly in United States and in Europe since the mid 1980s and the results have been highly encouraging. In these systems the conversion of solar energy into electricity is particularly efficient with a net average annual yield rate ranging between 18% and 23%, higher than any other solar energy system, and has attained a record rate of 29% for a brief time.

1.1. 2. Available Studies and Reports on DS and PT's costs

Although the extant literature about economic impacts of these two CSP technologies is relatively narrow, recent surge of publications about these two technologies shows increasing importance of these two sources of solar energy. Located papers about this field are mostly published after 2009, and related reports are published in last 10 years. Geographical distribution of studies shows that they are based on evidence from Mediterranean region (Spain, Algeria, Morocco and Turkey), Asia (China, India), Germany, Australia and Brazil. While economical analysis of these technologies in other geographical locations needs further attention.

Based upon available studies, in the following we will focus on comparative economic analysis of these technologies, first about retrieved papers and then available reports. Finally, we discuss about these studies and their results. However, since the electricity cost and land requirement are the two crucial parameters for our study, we have tried to highlight the importance of them in this report.

As far as unit cost (cost/kWh) calculations for comparative purposes, there are two basic approaches: The average annual cost per kWh, and the 'levelised' cost per kWh.

The ***average annual*** cost-per-kWh approach

It is the usual calculation procedure for a given CSP project or installation: First, as usual, to determine or forecast:

- the required initial investment (*INV*): basically the cost of the power-generation unit, modules or core equipment plus the installation works' costs, but also the costs of other complementary small equipment (which is usually referred to as 'balance of the system', 'bos').
- the system's annual operating & maintenance costs (*M*).
- an estimate for the system productive life (*n* years)
- a foprecast for the average annual electricity output or yield of the system, in kWh per year: (E); and
- an estimate of the annual financial costs (FC) associated to the required initial investment

And then to determine the average annual-costs of the system: $(INV/n + M + FC)$, and dived it by the expected annual average electricity output, *E*:

$$\text{Cost-per-kWh} = \frac{{}^{INV}\!/_{n} + M + FC}{E}$$

Where the first component of the numerator is the linear amortisation quota of the initial investment. It assumes that the useful life for all equipment/components is the same: the one estimnated for the power-generator unit/equipment, yielding an average of ***E*** kWh-per-year along ***n*** years. In the case some minor equipment (whith cost = ***inv*** €) have a lower useful life, that should be taken into account substituting in the above formula [*(INV-inv)/n* + *inv/m*], by *INV/n*; (being *m<n*).

The above is the usual calculation approach we can found implicitly in many articles, studies and reports –as we will see further on. However is also broadly used the approach of "Levelised Costs of Electricity, LCOE, or LCE). Thus, let's describe it.

The approach "***Levelised Cost of Electricity*** " (LCOE, or LCE, or LEC), for cost-per-kWh

In order to compare the cost of electricity from renewable energies, several ways are recommended by considering different parameters. In 2011, national renewable energy laboratory (NREL) in USA published a report about renewable energy cost modeling. This report provides an overview of all costing methods and taxonomy of all calculation methodologies. After discussing about discounted cash flow model (DCF), recovery factor analysis, simple payback and profitability index method, they recommend two main financial models that have been widely used in different renewable energies projects: Levelised cost of electricity (LCOE) and CREST model. System advisor model (SAM) is recommended for LCOE calculation which is intended to facilitate decision making for renewable energy experts from project managers and engineers to incentive program designers, technology developers, and researchers.

	SAM	**CREST**
Technology	Solar, wind, geothermal	Solar, wind, geothermal
Target Audience	Project managers, engineers, incentive program designers, technology developers, and researchers	State and local stakeholders involved in policy and rate analysis
Performance Inputs	Location-specific weather files for solar and wind; location-specific temperature and depth profiles for geothermal SAM allows user-defined technical inputs beyond cost (e.g., PV module type, wind turbine farm layout, and geothermal energy conversion type (flash or binary)	Simple capacity factor for solar, geothermal, and wind
Cost Input Methodology	"Bottom-up" input methodology for total installed cost	"Bottom-up" input methodology for total installed cost (allows for a "top-down" approach if better suited to the modeling needs)
Financial & Economic Model	Discounted cash flow (DCF) methodology Detailed and accurate tax representation of user-	Discounted cash flow (DCF) methodology Detailed and accurate tax representation of

	defined incentives Public, private, and 3rd party ownership structures Includes advanced financial analysis for the utility market Additional outputs include first-year PPA price, debt/equity ratio derived from DSCR requirement, etc.	user-defined incentives Public and private ownership structures
Model Transparency	SAM's cash flow models are not available for user review	CREST includes transparent cash flow statements
Bells & Whistles	Graphical representations of model outputs Built-in sensitivity analyses and tornado charts Allows users to set up data exchanges to add their own input for many variables	Graphical representations of model outputs

The other model, CREST, is a spreadsheet tool for renewable energy cost that simplifies policy and rate analysis for state and local stakeholder particularly when they need to design an effective policy or Feed-in-Tariff (FiT). Difference between these two models are summarized in Table.6[7](Gifford & Grace, 2011) . Nevertheless, the most accepted way for calculating the electricity cost by renewable energies is levelized cost of energy (LCOE). This model could be either simple or sophisticated, based on number of parameters we are willing to include in our calculation. Apparently our estimation is more accurate if we incorporate more parameters providing that we have access to required information which is not always a case. The formula used for calculating the LCOE of a given electricity-generation system is:

$$LOCE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where:

LCOE = the average lifetime levelized cost of electricity generation: €/kWh
It = investment expenditures in the year t; $\sum I_t =$ INV
Mt = operations and maintenance expenditures in the year t;
Ft = fuel expenditures in the year t;
Et = electricity generation in the year t;
r = discount rate; and
n = life of the system

Which, as can be seen, in comparison with the previous *annual-average-cost* approach, allows for two refinements: 1) to considere that *M* costs –in real terms, apart from inflation- may have some variation along the productive period; and 2) to account for some degree of decreasing in the system output, *E* (due to some degradation of the power-unit's yield)

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[7] https://financere.nrel.gov/finance/content/nrel-s-levelized-cost-energy-tools-which-one-right-you#comment-149

This formula is also recommended by International Renewable Energy Agency (IRENA) to make a standard evaluation of different technologies across different context. Recently new on-line applications facilitated this calculation by using pre-defined parameters. These applications are developed by National Renewable Energy Laboratory[8] and are reliable enough for simple estimation. But for more complex calculations with more customized calculation we need to rely on more detailed LCOE analysis.

Due to the fact that the model needs to be applied to a wide range of renewable technologies in different countries and regions, LCOE is relatively simplistic formula. But this has the extra advantage that the analysis is clear and simple to understand. Although more detailed LCOE analysis may seems more accurate, when it is not possible to robustly populate the model with assumptions or to differentiate assumptions based on real world data, then the "accuracy" of the approach can be misleading and more assumption results in a significantly higher overhead in terms of the granularity of assumptions required.

We need to note that LCOE has its shortcomings: It is only helpful for comparing different technologies on a cost basis, and it is not a calculation of feed-in-tariffs. For complex for feed-in-tariffs calculation we need to add other parameters such as self-consumption, tax laws and realized income. Moreover, the LCOE does not take into account the value of generated electricity within an energy system in a certain hour of a year and it makes no assumption about how generation station financed and the risk allocated to each parties (Kost, Mayer, & Philipps, 2013; Kost, Schlegl, Thomsen, Nold, & Mayer, 2012).

In order to compensate the limitations of LCOE it could be also applied the Simple *Payback* method (SPB) as well as the *Internal Rate of Return* method (IRR). The simple payback is calculated by dividing the initial equity investment by the estimated annual cash flow to equity. The value of simple payback is a conceptually easy-to-grasp description of the return of invested capital and normally is utilized by entities that plan to finance a project using internal funds and not incur project-level debt (Gifford & Grace, 2011). And as far as the *Internal Rate of Return*, or discounted cash-flow (DCF) analysis, it is method of calculating the *Net present value*, NPV, and IRR on a potential renewable energy investment by estimating future free cash flows to equity on a periodic (i.e., annual, quarterly, or monthly) basis, taking into consideration the time value of money. A DCF analysis can be used to calculate a project's IRR both before and after tax. Cash flows are estimated using project-specific revenue and expense forecasts, debt service obligations, depreciation schedules, and income tax assumptions (as applicable). A DCF analysis takes a project's operational and financing milestones—including evolving tax obligations—into account when estimating its NPV and IRR. The DCF method also is capable of recognizing constraints on project financing, such as minimum debt service coverage ratios, and time-sensitive operational events, such as major equipment repairs or replacements (e.g., inverter for solar and gearbox for wind). It is the most detailed methodology discussed here.

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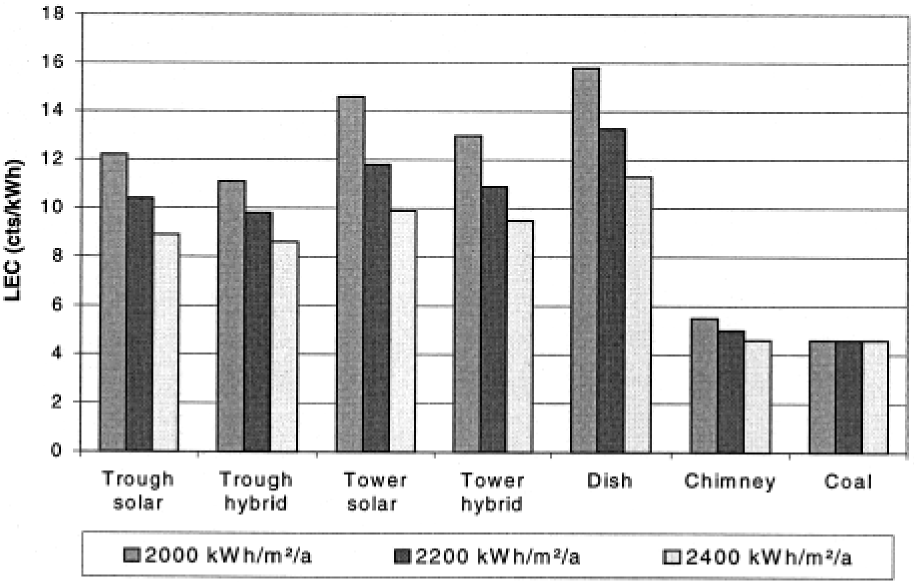
[8] http://www.nrel.gov/analysis/tech_lcoe.html

Published Papers (articles in specialised journals)

A number of papers have published about the economic analysis of concentrated solar power and its applications. Although these papers are not a detailed financial analysis of CSR projects, they provide clear, reliable and up-to-date information which can be used to evaluate the costs and performance of different renewable power generation technologies. For this paper work, about 11 papers are considered and they are analysed chronologically from 2000 till 2012.

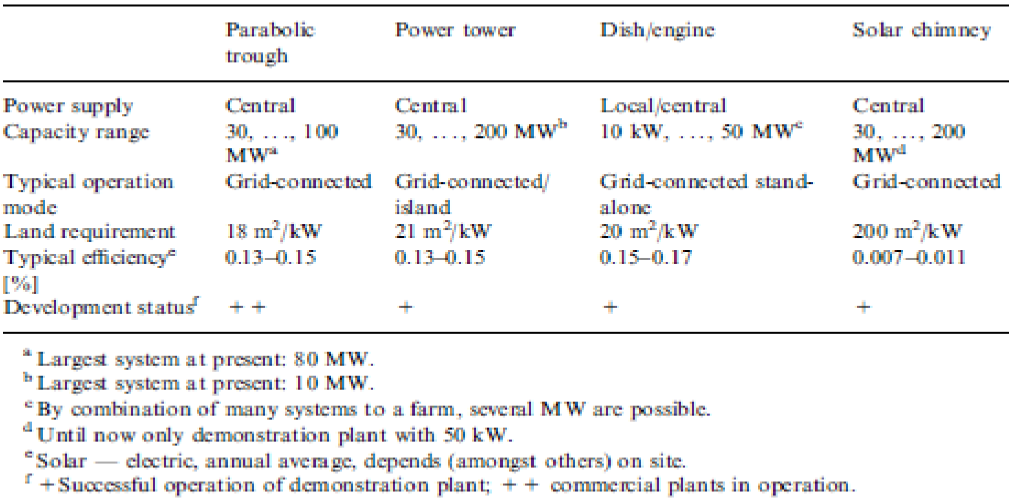
First paper is a pivotal study by Beerbaum and Weinrebe (2000), they have focused on the development of solar thermal generation. This comprehensive study provides a techno-economical evaluation of these technologies in India. The most applicable part of this study compares levelised electricity costs (LEC) for different available technological options for solar thermal electricity (figure 3). As you can understand from this figure the lowest level of electricity cost is related to Trough Solar with about 12 cts/kWh and the highest level is for Tower Solar and Dish with about 14 and 16 cts/kWh respectively.

Levelized Electricity Costs (LEC) for centralized electricity generation



Apart from LEC, other factors like capacity range, land requirement, and efficiency are considered in this analysis and its results are summarized in table 1.

Table 1. Comparison of investigated plants (Beerbaum and Weinrebe, 2000)

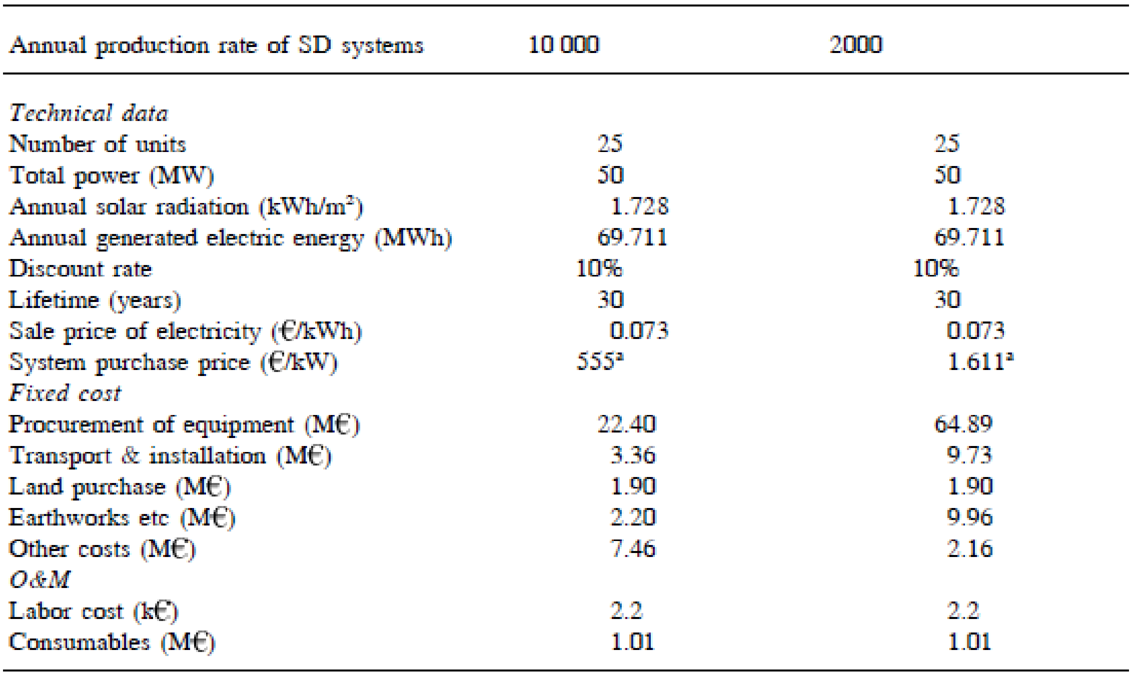


	Parabolic trough	Power tower	Dish/engine	Solar chimney
Power supply	Central	Central	Local/central	Central
Capacity range	30, …, 100 MW[a]	30, …, 200 MW[b]	10 kW, …, 50 MW[c]	30, …, 200 MW[d]
Typical operation mode	Grid-connected	Grid-connected/ island	Grid-connected stand-alone	Grid-connected
Land requirement	18 m^2/kW	21 m^2/kW	20 m^2/kW	200 m^2/kW
Typical efficiency[e] [%]	0.13–0.15	0.13–0.15	0.15–0.17	0.007–0.011
Development status[f]	+ +	+	+	+

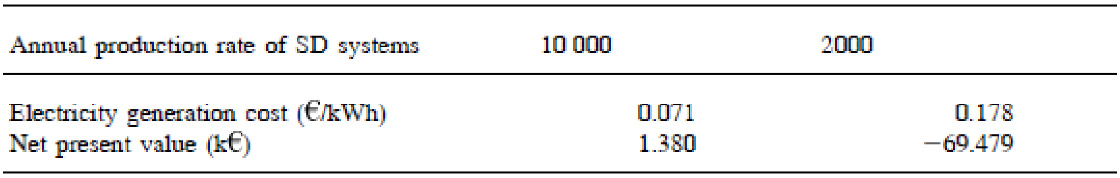
[a] Largest system at present: 80 MW.
[b] Largest system at present: 10 MW.
[c] By combination of many systems to a farm, several MW are possible.
[d] Until now only demonstration plant with 50 kW.
[e] Solar — electric, annual average, depends (amongst others) on site.
[f] +Successful operation of demonstration plant; + + commercial plants in operation.

Other study by Tsoutsos in 2003 argues about technical and economical evaluation of Dish- Stirling (in this study SD systems) technology in Cretan island at Mediterranean region, Greece. In this study they applied sensitivity analysis and also comparison with conventional energy systems. Results of this study underline the importance of market extension of this technology as competitive source of energy in electricity market. Results of this study as you can see in table.3 provide an economical evaluation and costs of this system with two production rate at 10,000 and 2000. It also calculated cost of electricity generation for 0.071 euro/kWh (with 10,000 production rate annually) and 0.178 euro/kWh (with 2000 production rate annually) as is shown in table 2.

Table 2. Feasibility study of Dish-Stirling technology (Tsoutsos, 2003)



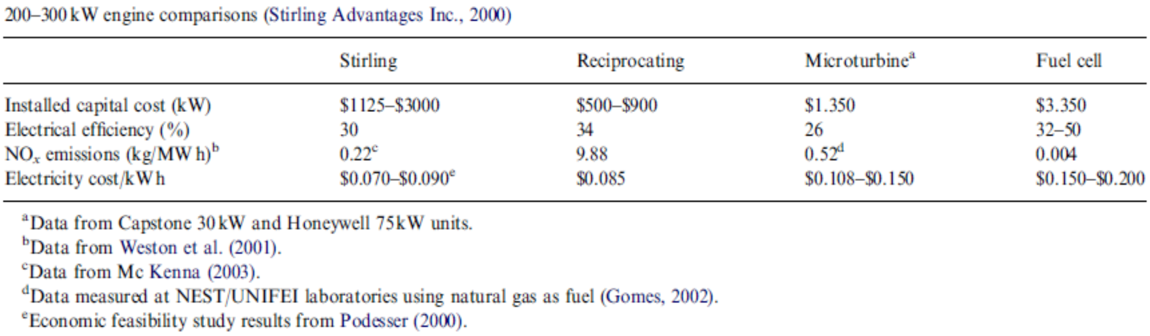
Annual production rate of SD systems	10 000	2000
Technical data		
Number of units	25	25
Total power (MW)	50	50
Annual solar radiation (kWh/m^2)	1.728	1.728
Annual generated electric energy (MWh)	69.711	69.711
Discount rate	10%	10%
Lifetime (years)	30	30
Sale price of electricity (€/kWh)	0.073	0.073
System purchase price (€/kW)	555[a]	1.611[a]
Fixed cost		
Procurement of equipment (M€)	22.40	64.89
Transport & installation (M€)	3.36	9.73
Land purchase (M€)	1.90	1.90
Earthworks etc (M€)	2.20	9.96
Other costs (M€)	7.46	2.16
O&M		
Labor cost (k€)	2.2	2.2
Consumables (M€)	1.01	1.01



Annual production rate of SD systems	10 000	2000
Electricity generation cost (€/kWh)	0.071	0.178
Net present value (k€)	1.380	−69.479

Moreover, Corria et al. in 2006 at Brazil have focused on Dish-Stirling technology and its advantages. Although this study discuss about various perspectives of this technology such as its technical and environmental factors, we just focused on its economic evaluation. As you can see in table.3 there is a comparison between this technology and other sources of energy. In this evaluation they consider different criteria like installed capital cost (kW), electrical efficiency (%) NO emission and electricity cost ($/kWh). Final result of this study shows electricity cost per kWh is between 0.070 and 0.090 $/kWh which is relatively lower than other studied technologies like Fuel cell, Reciprocating, and Microturbine.

Table 3. Corria et al., (2006)



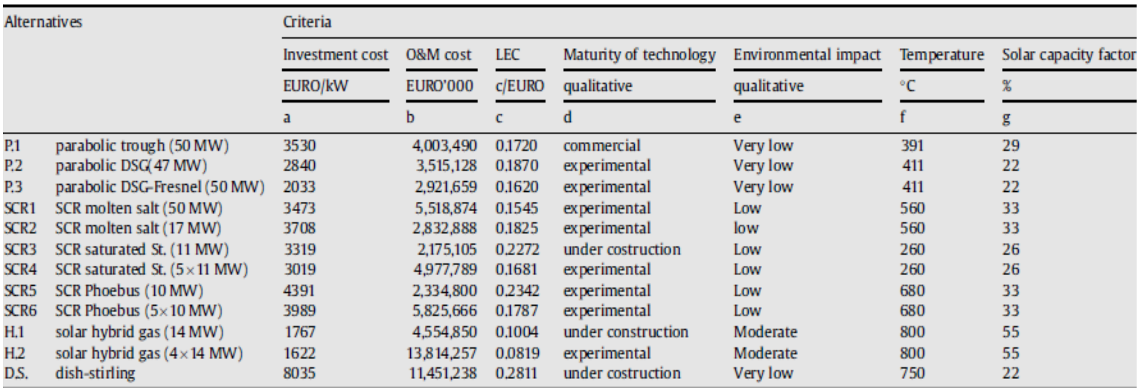
200–300 kW engine comparisons (Stirling Advantages Inc., 2000)

	Stirling	Reciprocating	Microturbine[a]	Fuel cell
Installed capital cost (kW)	$1125–$3000	$500–$900	$1.350	$3.350
Electrical efficiency (%)	30	34	26	32–50
NO_x emissions (kg/MW h)[b]	0.22[c]	9.88	0.52[d]	0.004
Electricity cost/kW h	$0.070–$0.090[e]	$0.085	$0.108–$0.150	$0.150–$0.200

[a] Data from Capstone 30 kW and Honeywell 75 kW units.
[b] Data from Weston et al. (2001).
[c] Data from Mc Kenna (2003).
[d] Data measured at NEST/UNIFEI laboratories using natural gas as fuel (Gomes, 2002).
[e] Economic feasibility study results from Podesser (2000).

In a comparative study among different CSR projects by Cavallero (2009), he recommends multi-criteria methods to evaluate cost, performance and environmental factors of these technologies. This study is based on Pitz-paal, Deresch and Milow (2003) report about European Concentrated Solar Thermal Road-Mapping and available data in this study refer to current projects in EU region. In this study they put emphasize on multi-criteria evaluation of these systems and they suggest applying criteria such as Investment Cost, O&M Cost (operation and maintenance), Levelised Electricity Cost (LEC), Environmental Impact and Solar Capacity Factor. Evaluation of these suggested criteria are summarized in table 4.

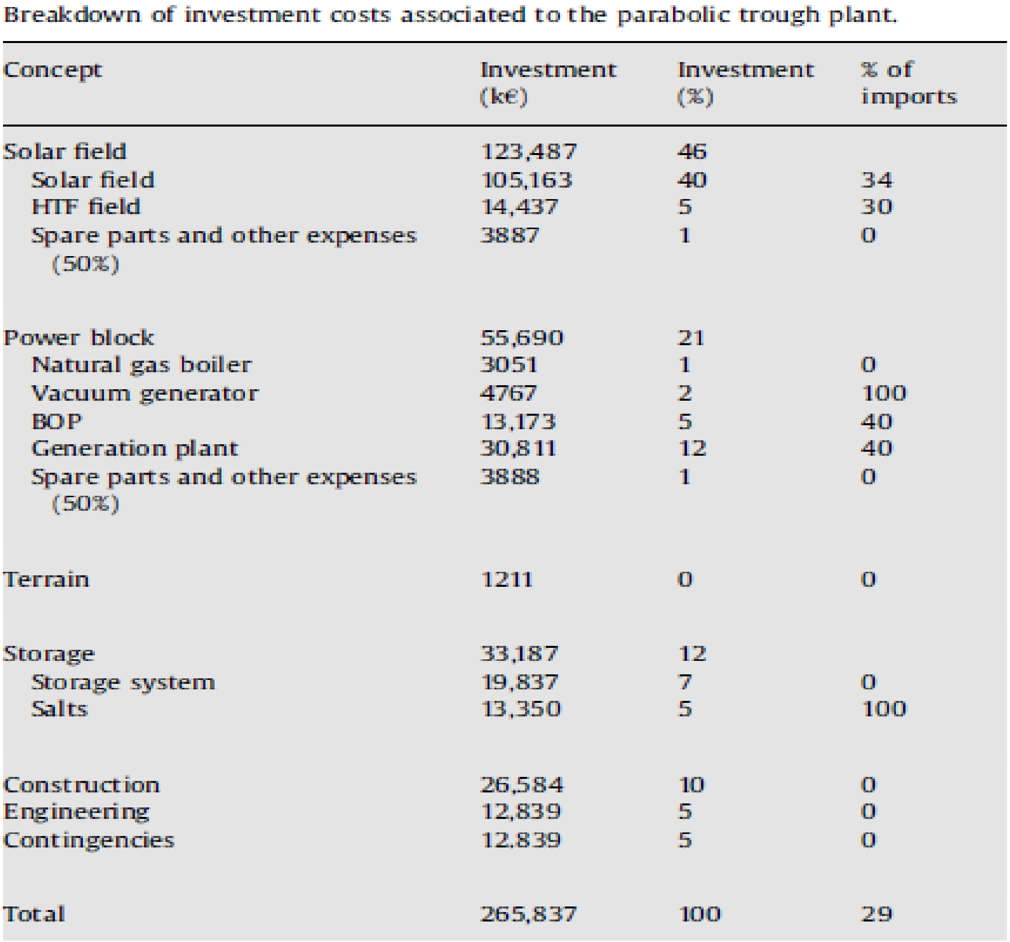
Table 4. Cavallaro (2009) comparative report (Adopted from Pitz-paal, Deresch and Milow, 2003)



Alternatives		Criteria						
		Investment cost	O&M cost	LEC	Maturity of technology	Environmental impact	Temperature	Solar capacity factor
		EURO/kW	EURO'000	c/EURO	qualitative	qualitative	°C	%
		a	b	c	d	e	f	g
P.1	parabolic trough (50 MW)	3530	4,003,490	0.1720	commercial	Very low	391	29
P.2	parabolic DSG(47 MW)	2840	3,515,128	0.1870	experimental	Very low	411	22
P.3	parabolic DSG-Fresnel (50 MW)	2033	2,921,659	0.1620	experimental	Very low	411	22
SCR1	SCR molten salt (50 MW)	3473	5,518,874	0.1545	experimental	Low	560	33
SCR2	SCR molten salt (17 MW)	3708	2,832,888	0.1825	experimental	low	560	33
SCR3	SCR saturated St. (11 MW)	3319	2,175,105	0.2272	under costruction	Low	260	26
SCR4	SCR saturated St. (5 × 11 MW)	3019	4,977,789	0.1681	experimental	Low	260	26
SCR5	SCR Phoebus (10 MW)	4391	2,334,800	0.2342	experimental	Low	680	33
SCR6	SCR Phoebus (5 × 10 MW)	3989	5,825,666	0.1787	experimental	Low	680	33
H.1	solar hybrid gas (14 MW)	1767	4,554,850	0.1004	under construction	Moderate	800	55
H.2	solar hybrid gas (4 × 14 MW)	1622	13,814,257	0.0819	experimental	Moderate	800	55
D.S.	dish-stirling	8035	11,451,238	0.2811	under costruction	Very low	750	22

Other study at Spain by Caldes et al., (2009) put emphasise on socio-economic impacts of solar thermal electricity deployment. In this study by applying input-output analysis (I/O) they conclude that because of generated jobs and also market demand, the socio-economic effect of renewable energy plan is remarkable. The more applicable part of this study, analyse the investment cost of 50MW Parabolic Trough power plant and 17MW Tower Plant. For parabolic trough power plant, costs of investment include: solar field accounts for 46% of the total investment cost, power block for 21%, storage for 12%, construction for 10%, and the remaining 10% accounts for engineering costs and contingencies (See table 5 and table 6).

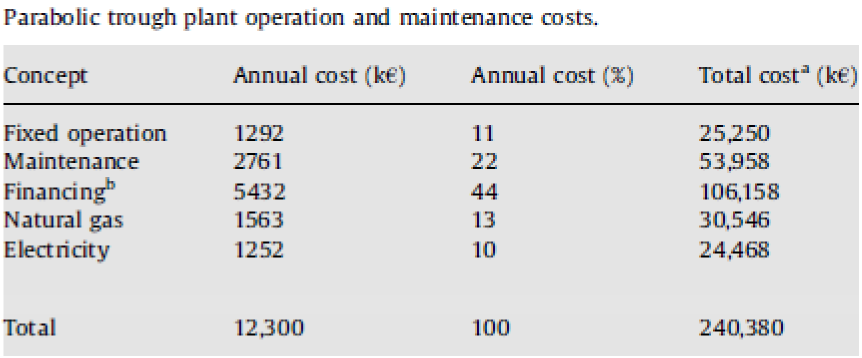
Table 5. Investment cost analysis of parabolic trough plant (Caldes et al., 2009)



Breakdown of investment costs associated to the parabolic trough plant.

Concept	Investment (k€)	Investment (%)	% of imports
Solar field	123,487	46	
Solar field	105,163	40	34
HTF field	14,437	5	30
Spare parts and other expenses (50%)	3887	1	0
Power block	55,690	21	
Natural gas boiler	3051	1	0
Vacuum generator	4767	2	100
BOP	13,173	5	40
Generation plant	30,811	12	40
Spare parts and other expenses (50%)	3888	1	0
Terrain	1211	0	0
Storage	33,187	12	
Storage system	19,837	7	0
Salts	13,350	5	100
Construction	26,584	10	0
Engineering	12,839	5	0
Contingencies	12.839	5	0
Total	265,837	100	29

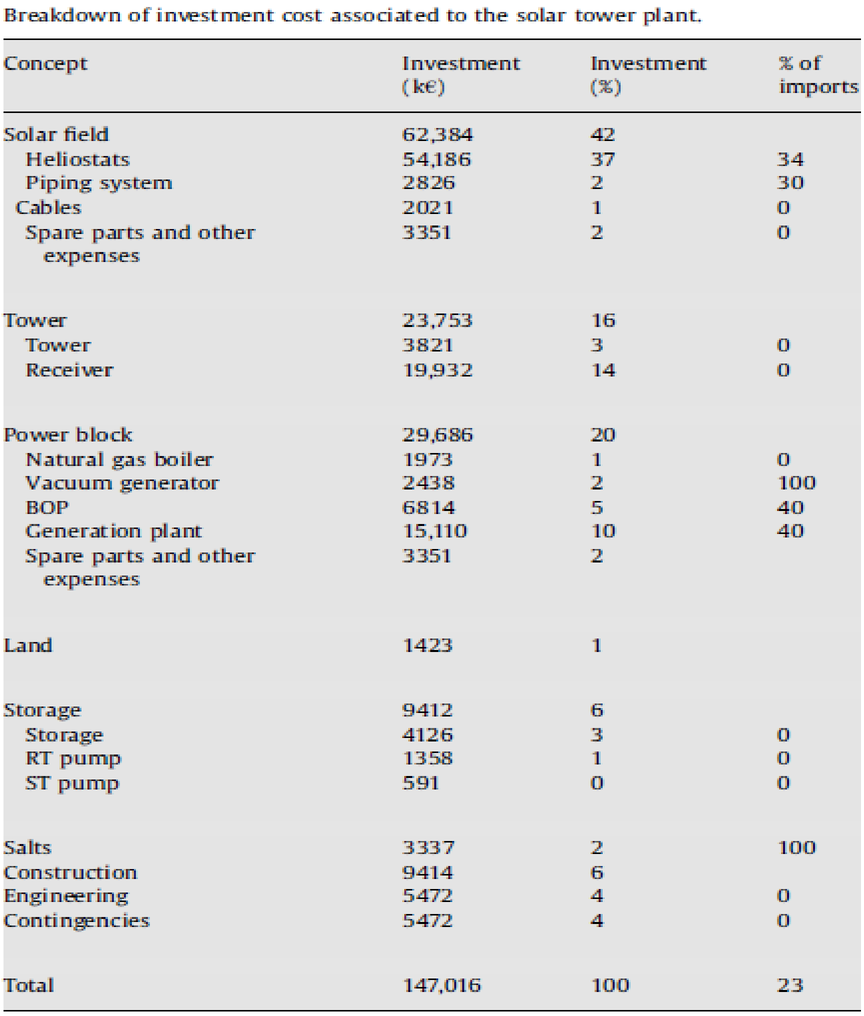
Table 6. Investment cost analysis of parabolic trough plant (Caldes et al., 2009)


Parabolic trough plant operation and maintenance costs.

Concept	Annual cost (k€)	Annual cost (%)	Total cost[a] (k€)
Fixed operation	1292	11	25,250
Maintenance	2761	22	53,958
Financing[b]	5432	44	106,158
Natural gas	1563	13	30,546
Electricity	1252	10	24,468
Total	12,300	100	240,380

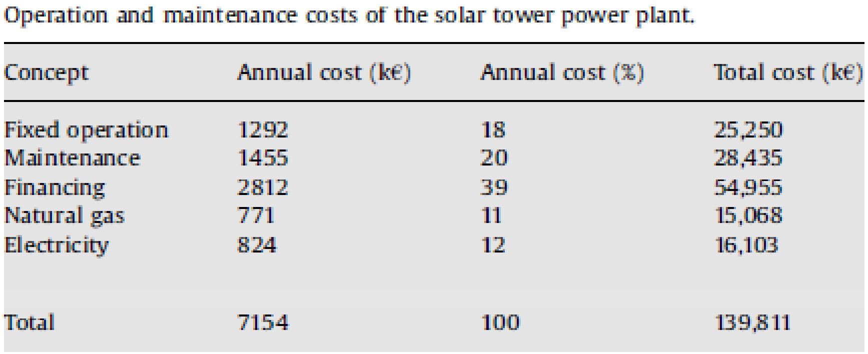
While for Tower Plant these costs consist of: solar field accounts for 42% of the investment, power block for 20%, tower and receptor for 16%, storage system for 6%, construction for 6%, and the remaining 8% accounts for engineering and contingencies costs (See table 7 and table 8).

Table 7. Investment cost analysis of solar tower plant (Caldes et al., 2009)


Breakdown of investment cost associated to the solar tower plant.

Concept	Investment (k€)	Investment (%)	% of imports
Solar field	62,384	42	
Heliostats	54,186	37	34
Piping system	2826	2	30
Cables	2021	1	0
Spare parts and other expenses	3351	2	0
Tower	23,753	16	
Tower	3821	3	0
Receiver	19,932	14	0
Power block	29,686	20	
Natural gas boiler	1973	1	0
Vacuum generator	2438	2	100
BOP	6814	5	40
Generation plant	15,110	10	40
Spare parts and other expenses	3351	2	
Land	1423	1	
Storage	9412	6	
Storage	4126	3	0
RT pump	1358	1	0
ST pump	591	0	0
Salts	3337	2	100
Construction	9414	6	
Engineering	5472	4	0
Contingencies	5472	4	0
Total	147,016	100	23

Table 8. Investment cost analysis of solar tower plant (Caldes et al., 2009)



Operation and maintenance costs of the solar tower power plant.

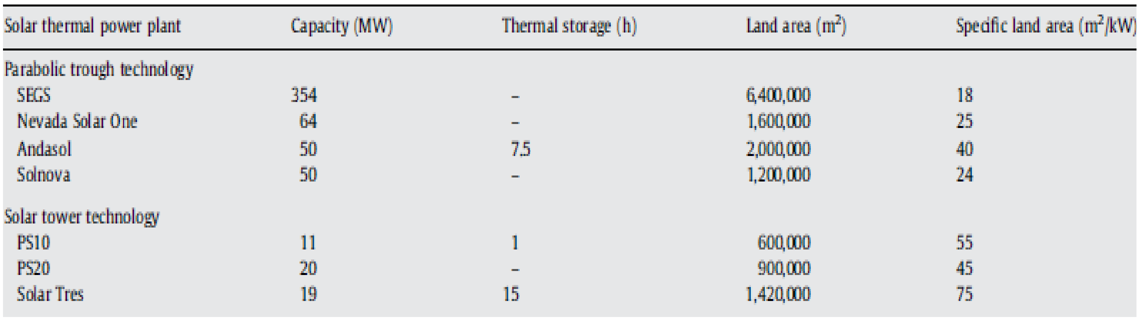
Concept	Annual cost (k€)	Annual cost (%)	Total cost (k€)
Fixed operation	1292	18	25,250
Maintenance	1455	20	28,435
Financing	2812	39	54,955
Natural gas	771	11	15,068
Electricity	824	12	16,103
Total	7154	100	139,811

By comparing these two plants we can conclude that percent of investment cost for parabolic trough technology in solar field (46%) and storage is higher than solar power tower. So this technology is more capital intensive than Power Tower.

In another study at Mediterranean region, Poullikkas (2009) studied economic feasibility of parabolic trough technology in Cyprus Island. For accurate cost-benefit analysis of this technology various parameters such as: plant capacity, capital investment, operating hours, carbon dioxide emission trading system price are considered. Results of this study, by considering current regulations and tariffs at this context, indicate the profitability of these projects under certain conditions.

Interesting part of this study is a comparative land requirement analysis. In this analysis, according to previous projects, he compared the required land for Parabolic Trough and Solar Tower technologies. Parabolic Troughs requires a land area of approximately 25 m2/kW, in the case where no thermal storage is integrated. Solar towers have the highest requirement of approximately 45 m2/kW, in the case where no thermal storage is integrated (table.9). The rest of the paper discuss about the feasibility study and cost benefit analysis of this system.

Table 9. Land requirement in previous parabolic trough projects (Poullikkas, 2009)

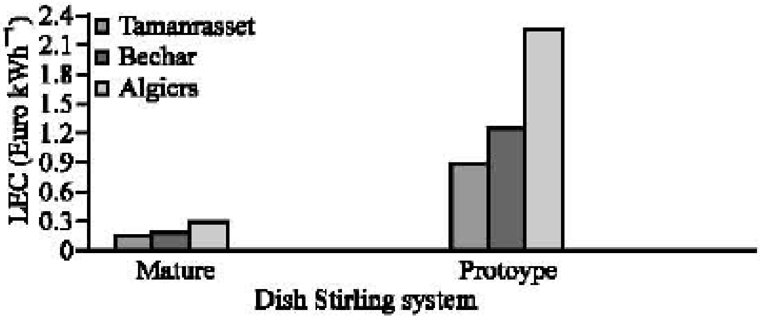


Solar thermal power plant	Capacity (MW)	Thermal storage (h)	Land area (m^2)	Specific land area (m^2/kW)
Parabolic trough technology				
SEGS	354	–	6,400,000	18
Nevada Solar One	64	–	1,600,000	25
Andasol	50	7.5	2,000,000	40
Solnova	50	–	1,200,000	24
Solar tower technology				
PS10	11	1	600,000	55
PS20	20	–	900,000	45
Solar Tres	19	15	1,420,000	75

In a research at Algeria by Abbas et al. (2009) they studied the techno-economic evaluation of solar dish Stirling system. This study represents application of two configurations of this technology (prototype and mature). Results of this study put emphasize upon competitive advantage of this technology in comparison with photo voltaic and conventional electricity generation technologies.

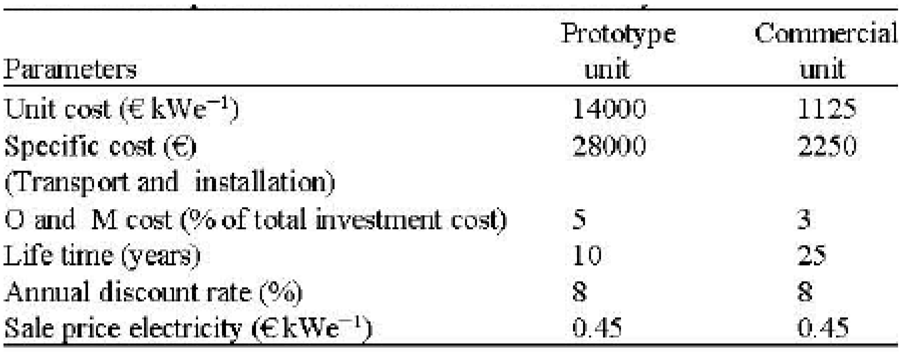
Economic performance of this solar power plant is indicated by levelised electricity cost (LEC) which is the most common index (figure.4).

Figure 4. LEC evaluated in three sites (Abbas et al., 2009)



Other contribution of this study is to show differences between the prototype and mature configurations. As it is shown in figure.4 LEC in prototype Dish Stirling system is about 0.88 €KW-1, 1.25 €KW-1, and 2.25 €KW-1 in three different sites, while these costs in mature configuration reduced to 0.15, 0.17 and 0.29 €KW-1 respectively. Related assumptions to this calculation are shown in table 10.

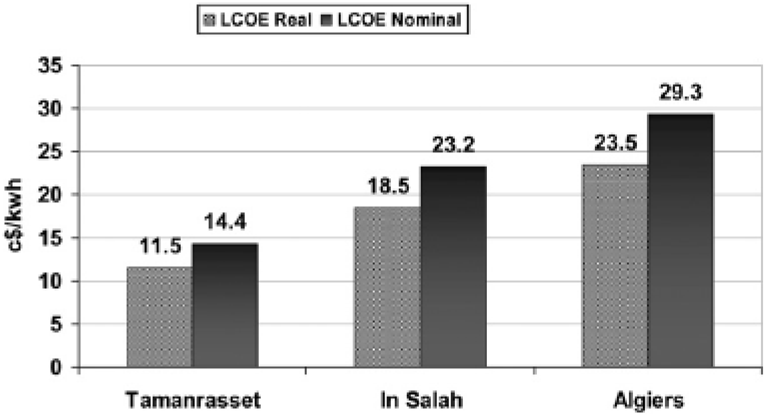
Table10. Assumptions for economic evaluation in mature and prototype configuration



Parameters	Prototype unit	Commercial unit
Unit cost (€ kWe^{-1})	14000	1125
Specific cost (€) (Transport and installation)	28000	2250
O and M cost (% of total investment cost)	5	3
Life time (years)	10	25
Annual discount rate (%)	8	8
Sale price electricity (€ kWe^{-1})	0.45	0.45

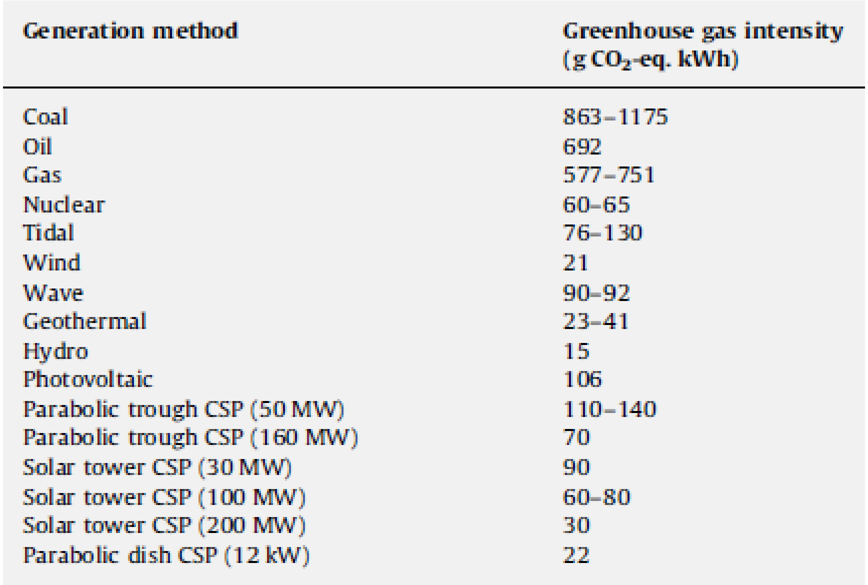
Latest published paper about the similar project (Abbas et al., 2011), reports a techno-economical assessment of 100 MW Dish Stirling technology using hydrogen as working fluid for centralized electricity production located in three typical sites of each geographical regions of Algeria (Algiers, In Salah and Tamanrasset). In this study they evaluate the monthly energy production, annual energy output and the Levelised Cost of Energy (LCOE). Result of this study make comparison between these three sites of power generation(Figure.5). As you can see in this table Tamanrasset shows lowest levelized electricity cost(because of higher level of sun radiation).

Figure 5. LCOE for the plant proposed in the three sites (Abbas et al., 2011)



Other research by Clifton and Bouroff (2010) discuss about the importance of concentrated solar power plant (CSR) in rural area of Australia. Results of this study underline the importance of this technology in rural development and also suggest further policy regime development which actively support and stimulate CSP. According to Lenzen(1999) and Lenzen et al. (2006), greenhouse gas emission intensity regarding various electricity generation method are reported in this study (see tabel.11).

Table 11. Comparative analysis of greenhouse emission/kWh

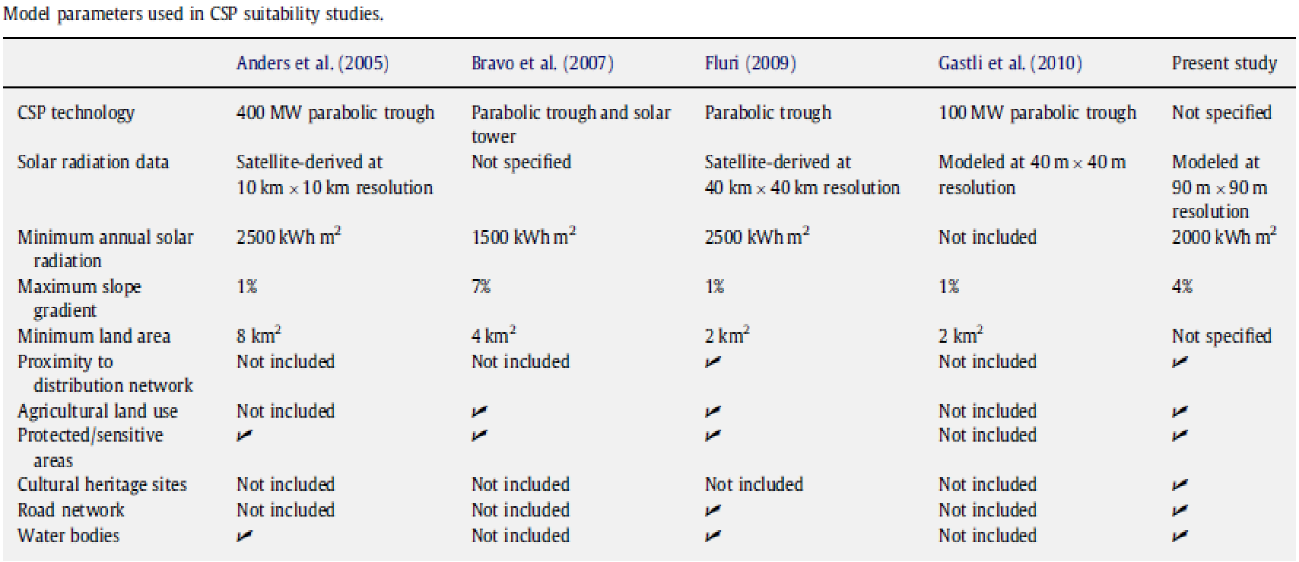


Generation method	Greenhouse gas intensity (g CO_2-eq. kWh)
Coal	863–1175
Oil	692
Gas	577–751
Nuclear	60–65
Tidal	76–130
Wind	21
Wave	90–92
Geothermal	23–41
Hydro	15
Photovoltaic	106
Parabolic trough CSP (50 MW)	110–140
Parabolic trough CSP (160 MW)	70
Solar tower CSP (30 MW)	90
Solar tower CSP (100 MW)	60–80
Solar tower CSP (200 MW)	30
Parabolic dish CSP (12 kW)	22

As it may be see in this table, the lowest level of carbon emission is related to Hydro, Wind and Parabolic dish respectively. While it is relatively higher for other commonly known solar power electricity generation methods such as: solar tower (30-90 gCO2-eq. KWh) parabolic trough (70-140 gCO2-eq. KWh) and photo voltaic (106 gCO2-eq. KWh).

This study also makes comparison between different parabolic trough projects in USA and Australia regarding model parameters they have used to evaluate Parabolic Trough method for electricity generation. In these studies' evaluation, they consider the minimum land area, kind of technology and proximity to distribution network (see table 12).

Table 12. Parameters used in CSP suitability studies (Clifton and Bouroff, 2010)

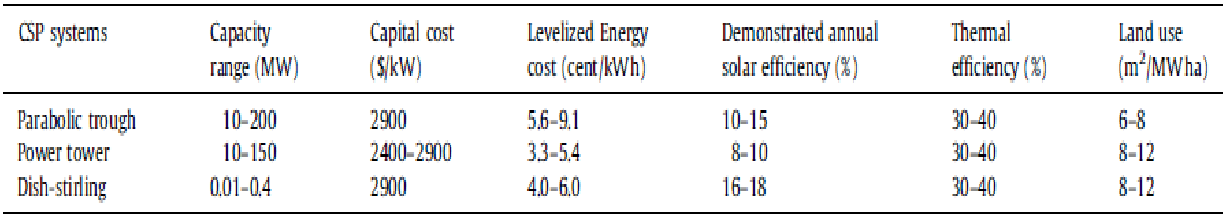


Model parameters used in CSP suitability studies.

	Anders et al. (2005)	Bravo et al. (2007)	Fluri (2009)	Gastli et al. (2010)	Present study
CSP technology	400 MW parabolic trough	Parabolic trough and solar tower	Parabolic trough	100 MW parabolic trough	Not specified
Solar radiation data	Satellite-derived at 10 km × 10 km resolution	Not specified	Satellite-derived at 40 km × 40 km resolution	Modeled at 40 m × 40 m resolution	Modeled at 90 m × 90 m resolution
Minimum annual solar radiation	2500 kWh m^2	1500 kWh m^2	2500 kWh m^2	Not included	2000 kWh m^2
Maximum slope gradient	1%	7%	1%	1%	4%
Minimum land area	8 km^2	4 km^2	2 km^2	2 km^2	Not specified
Proximity to distribution network	Not included	Not included	✓	Not included	✓
Agricultural land use	Not included	✓	✓	Not included	✓
Protected/sensitive areas	✓	✓	✓	Not included	✓
Cultural heritage sites	Not included	Not included	Not included	Not included	✓
Road network	Not included	Not included	✓	Not included	✓
Water bodies	✓	Not included	✓	Not included	✓

In 2011, Kaygusuz studied the potential of CSP technology in Turkey and also suggests some strategies to promote the development of CSP technology. For further elaboration this study provide performance data for various concentrating solar power technology based on IEA technology roadmap report on 2010.

Table 13. Performance data for three CSP system designs (IEA, 2010)



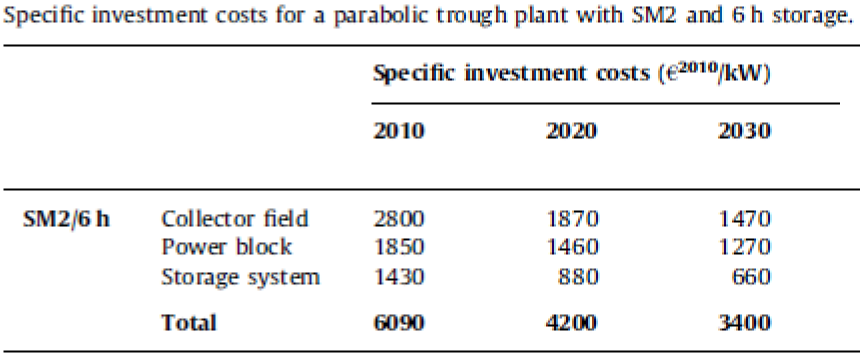
CSP systems	Capacity range (MW)	Capital cost ($/kW)	Levelized Energy cost (cent/kWh)	Demonstrated annual solar efficiency (%)	Thermal efficiency (%)	Land use (m^2/MWha)
Parabolic trough	10–200	2900	5.6–9.1	10–15	30–40	6–8
Power tower	10–150	2400–2900	3.3–5.4	8–10	30–40	8–12
Dish-stirling	0.01–0.4	2900	4.0–6.0	16–18	30–40	8–12

Results of this performance evaluation show the levelised energy cost (LEC), capital cost, capacity range, land use, and etc. for three types of CSP systems. LEC is lower for Dish Stirling than the Parabolic Trough, while the Power Tower is the most cost-effective technology. On the other hand, land usage is lower for Parabolic Trough and the capital cost is almost the same for these three types of systems.

Brand et al. (2012), in a study about the integration of CSP to the conventional electricity system, provide an evaluation of the Parabolic Trough technology in Morocco and Algeria and they make comparison between this technology and other kinds of renewable energy technologies: Photo Voltaic (PV), Power Plants and Wind Farms. Although the aim of their study is integration of these technologies to conventional electricity system, comparison of the specific investment costs of these technologies is highlighted in this research. As you can see in table.14 and table.15, they represent the current investment costs and future overview of these technologies. This comparison shows that investment costs for Parabolic Trough technology is relatively higher than the other two discussed technologies. While the specific investment cost of Parabolic Trough is 6090 Euro/kW, the PV power plant costs is 2500 Euro/MW and for Wind farms is 1150 Euro/ MW in these countries.

Result of this study anticipates that by developing Parabolic Trough technology its investment costs will decrease to 3400 (Euro/kW) till 2030. However, it would be still more costly in comparison with PV (1000 Euro/MW) and Wind farms (930 Euro/MW).

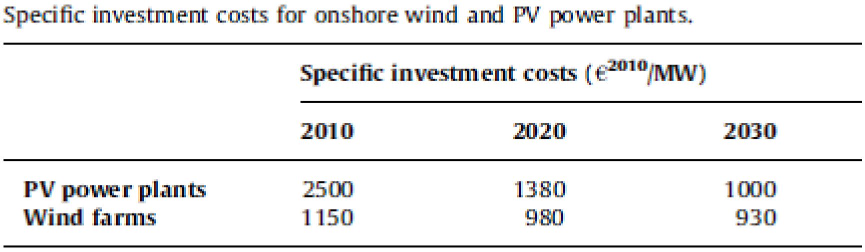
Table 14. Brand et al., (2012)



Specific investment costs for a parabolic trough plant with SM2 and 6 h storage.

		Specific investment costs (€^{2010}/kW)		
		2010	**2020**	**2030**
SM2/6 h	Collector field	2800	1870	1470
	Power block	1850	1460	1270
	Storage system	1430	880	660
	Total	**6090**	**4200**	**3400**

Table 15. Brand Et al., (2012)



Specific investment costs for onshore wind and PV power plants.

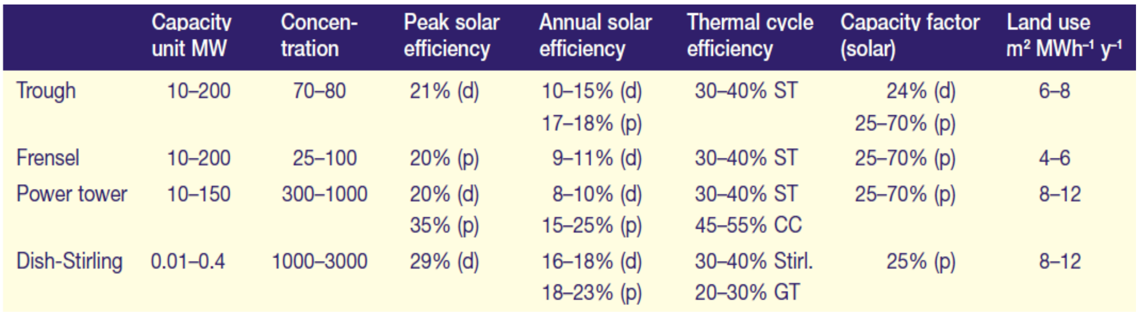
	Specific investment costs (€^{2010}/MW)		
	2010	**2020**	**2030**
PV power plants	2500	1380	1000
Wind farms	1150	980	930

Retrieved Reports (from specialised institutions)

Apart from papers published in journals, which have been reviewed above, reports by specialised entities are the more common way that contributes to body of knowledge based on evidences from different ongoing projects. Now we focus on the most important reports that previous papers tend to refer to.

One of these reports by institute of Technical Thermodynamics (DLR) in Ingenia publication, outline considerable potential of concentrated solar power for alleviating the constant pressure on limited natural resources. In part of this study that is related to our subject, they provide a table to compare the performance data regarding various CSP methods. As it is evident in table.19, we can see performance differences between various CSP technologies by considering different parameters such as land usage, capacity and efficiency. According to this report Fresnel and Trough technologies shows lower level of land usage, while annual solar efficiency of Power Tower and Dish-Stirling technologies are higher than the others.

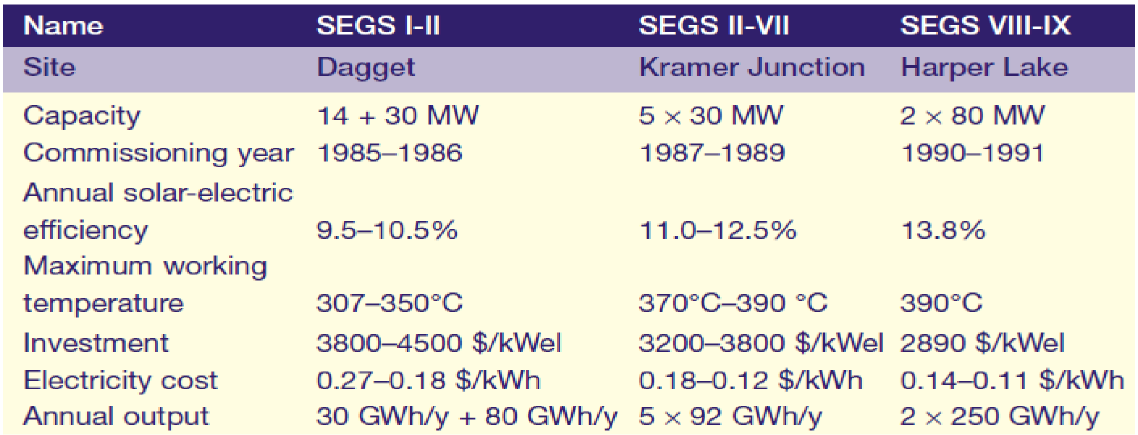
Table.19 performance data for various CSP technologies (adopted from, Muller-Steinhagen H, Trieb, 2004)



	Capacity unit MW	Concen-tration	Peak solar efficiency	Annual solar efficiency	Thermal cycle efficiency	Capacity factor (solar)	Land use $m^2\ MWh^{-1}\ y^{-1}$
Trough	10–200	70–80	21% (d)	10–15% (d) 17–18% (p)	30–40% ST	24% (d) 25–70% (p)	6–8
Frensel	10–200	25–100	20% (p)	9–11% (d)	30–40% ST	25–70% (p)	4–6
Power tower	10–150	300–1000	20% (d) 35% (p)	8–10% (d) 15–25% (p)	30–40% ST 45–55% CC	25–70% (p)	8–12
Dish-Stirling	0.01–0.4	1000–3000	29% (d)	16–18% (d) 18–23% (p)	30–40% Stirl. 20–30% GT	25% (p)	8–12

However, this report is for 2004 and some important parameters like levelised electricity costs (LEC) and investment cost are discussed about nine SEGS plants at California, USA (table.20). This evaluation is based on 1985 till 1991 data, which is not relatively up-to-date and accurate. So it needs to be updated regarding new projects.

Table.20. SEGS plants performance data



Name	SEGS I-II	SEGS II-VII	SEGS VIII-IX
Site	Dagget	Kramer Junction	Harper Lake
Capacity	14 + 30 MW	5 × 30 MW	2 × 80 MW
Commissioning year	1985–1986	1987–1989	1990–1991
Annual solar-electric efficiency	9.5–10.5%	11.0–12.5%	13.8%
Maximum working temperature	307–350°C	370°C–390 °C	390°C
Investment	3800–4500 $/kWel	3200–3800 $/kWel	2890 $/kWel
Electricity cost	0.27–0.18 $/kWh	0.18–0.12 $/kWh	0.14–0.11 $/kWh
Annual output	30 GWh/y + 80 GWh/y	5 × 92 GWh/y	2 × 250 GWh/y

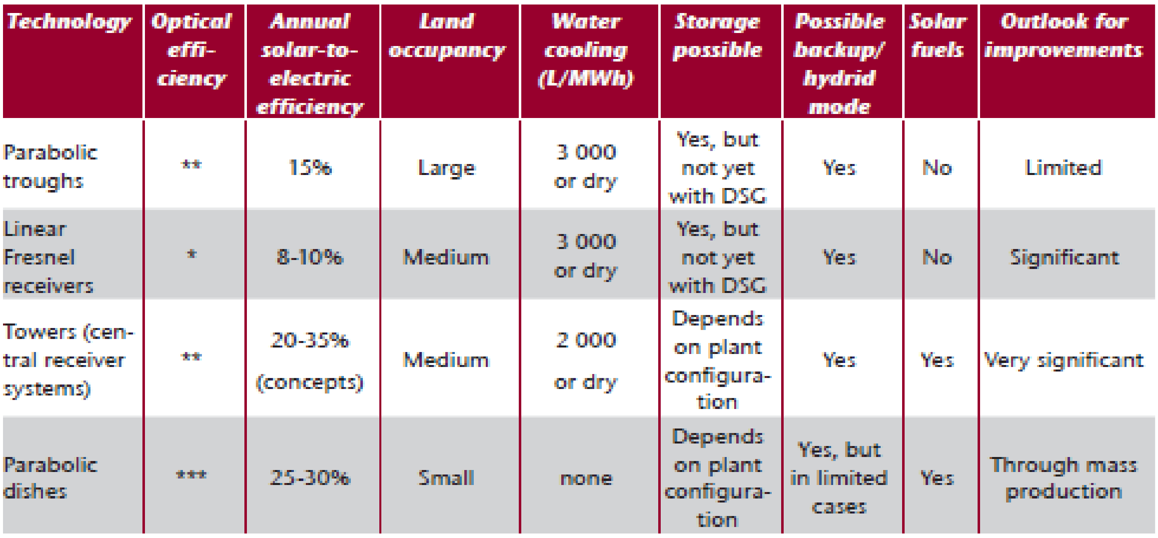
In the same year (2004), this centre also published another report about European Concentrated Solar Thermal Road-Mapping under the title of Ecostar. This comprehensive report introduces LEC as a methodology for cost study according to simplified IEA method. Comparison of different technical innovation about CSP is the main goal of this report. Moreover, the reference size of all systems is assumed to be 50 MW. According to this data, the most interesting part of this report is related to LEC calculation for a Single 50 MW reference system and LEC for Power plant (see table 21). As you can see in this table LEC for single reference system with Parabolic Trough technology is 0.172 €/kWhe and it would increase to 0.281 €/kWhe if we want apply it to Dish-Stirling technology.

Table.21.Ecostar Projects

Technology	Parabolic trough / HTF	Parabolic trough DSG	Molten salt Central receiver system	Saturated steam central receiver system	Atmospheric air central receiver system	Pressurized air central receiver system	Dish engine System
LEC for a single ECOSTAR reference system, solar-only	0.172 €/kWhe	0.187 €/kWhe	0.183 €/kWhe	0.241 €/kWh	0.234 €/kWhe	0.147 €/kWhe (0.1 €/kWhe)	0.281 €/kWhe
LEC for power plant park consisting of several reference systems with total capacity of 50 MW, solar-only	0.172 €/kWhe	0.162 €/kWhe	0.155 €/kWhe	0.169 €/kWhe	0.179 €/kWhe	0.139 €/kWhe (0.082 €/kWhe)	0.193 €/kWhe
Size of the Reference System	50 MWe	10 × 4.7 MWe	3 × 17 MWe	5 × 11 MWe	10 × 4.7 MWe	4 × 14.6 MWe	2907 × 25 kWe

More recently, the most referred report is technology roadmap of concentrating solar power by IEA (international energy agency). This roadmap starts with the status of CSP today, including considerations relative to the solar resource, current technologies and equipping CSP. The roadmap then sketches a vision of future large-scale use of CSP, includes an overview of the economic perspectives for CSP till 2050 and milestones for technology improvements are then described. The roadmap concludes with the policy framework required to support CSP technologies. However, the represented data in this report are more general information about this technology, without many details. As you can see in table.22 comparison of various CSP methods are discussed based on relatively qualitative data, except from annual efficiency and water cooling.

Table.22 comparison of main CSP technologies

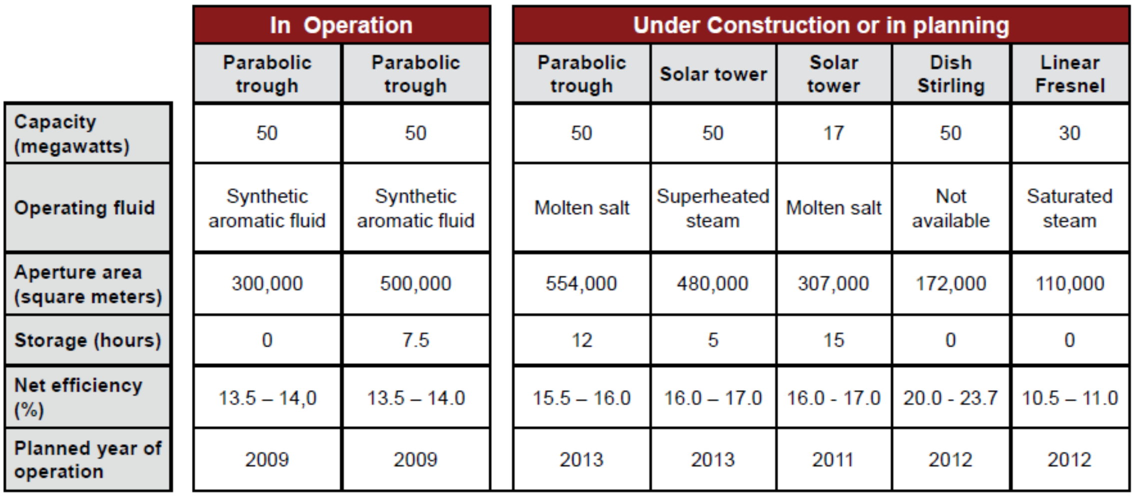


Technology	*Optical effi-ciency*	*Annual solar-to-electric efficiency*	*Land occupancy*	*Water cooling (L/MWh)*	*Storage possible*	*Possible backup/ hydrid mode*	*Solar fuels*	*Outlook for improvements*
Parabolic troughs	**	15%	Large	3 000 or dry	Yes, but not yet with DSG	Yes	No	Limited
Linear Fresnel receivers	*	8-10%	Medium	3 000 or dry	Yes, but not yet with DSG	Yes	No	Significant
Towers (cen-tral receiver systems)	**	20-35% (concepts)	Medium	2 000 or dry	Depends on plant configura-tion	Yes	Yes	Very significant
Parabolic dishes	***	25-30%	Small	none	Depends on plant configura-tion	Yes, but in limited cases	Yes	Through mass production

Another report by ESTELA under the title of Solar Thermal Electricity 2025 is published in 2010. This is a report by CIEMAT, Plataforma Solar de Almeria, CTAER,

Universidad de Sevilla, CENER (Spanish National Renewable Energy Centre). This report considered various ESTELA projects base plants as ongoing projects and under construction or future plant which are shown in table 23. Analysis of projects are based on interviews with participating companies and partners such as research institutes, technology developers, component manufacturers, plant developers, banks, governmental Institutions, industry associations, international institutions to prepare solar thermoelectric energy(STE) road map.

Table.23 Considered based plants.

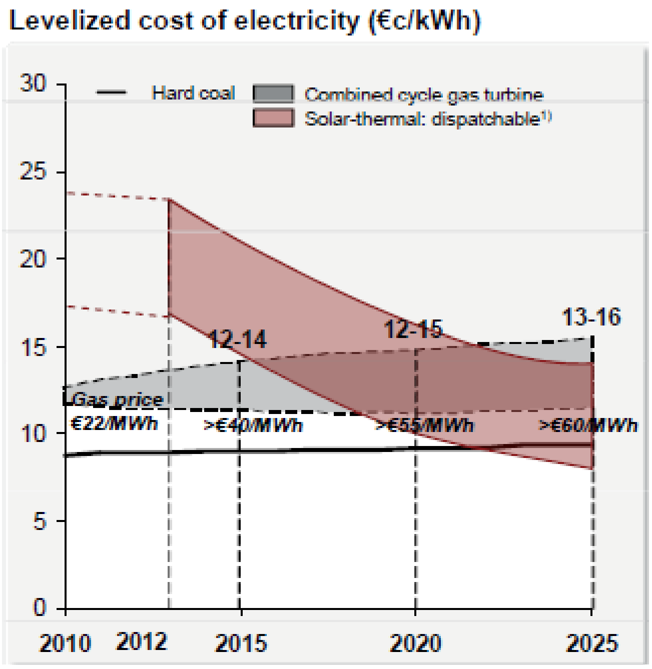


	In Operation		Under Construction or in planning				
	Parabolic trough	**Parabolic trough**	**Parabolic trough**	**Solar tower**	**Solar tower**	**Dish Stirling**	**Linear Fresnel**
Capacity (megawatts)	50	50	50	50	17	50	30
Operating fluid	Synthetic aromatic fluid	Synthetic aromatic fluid	Molten salt	Superheated steam	Molten salt	Not available	Saturated steam
Aperture area (square meters)	300,000	500,000	554,000	480,000	307,000	172,000	110,000
Storage (hours)	0	7.5	12	5	15	0	0
Net efficiency (%)	13.5 – 14,0	13.5 – 14.0	15.5 – 16.0	16.0 – 17.0	16.0 - 17.0	20.0 - 23.7	10.5 – 11.0
Planned year of operation	2009	2009	2013	2013	2011	2012	2012

However, this study more generally shows CSP technology and its comparison with other technologies. More importantly, part of this study makes comparison between solar thermoelectric technology (STE) and cost road map to extrapolate the expected levelised energy cost (here LOCE) evolution. This assessment helps us about long-term positing of this energy source among other sources of energy and its competitiveness.

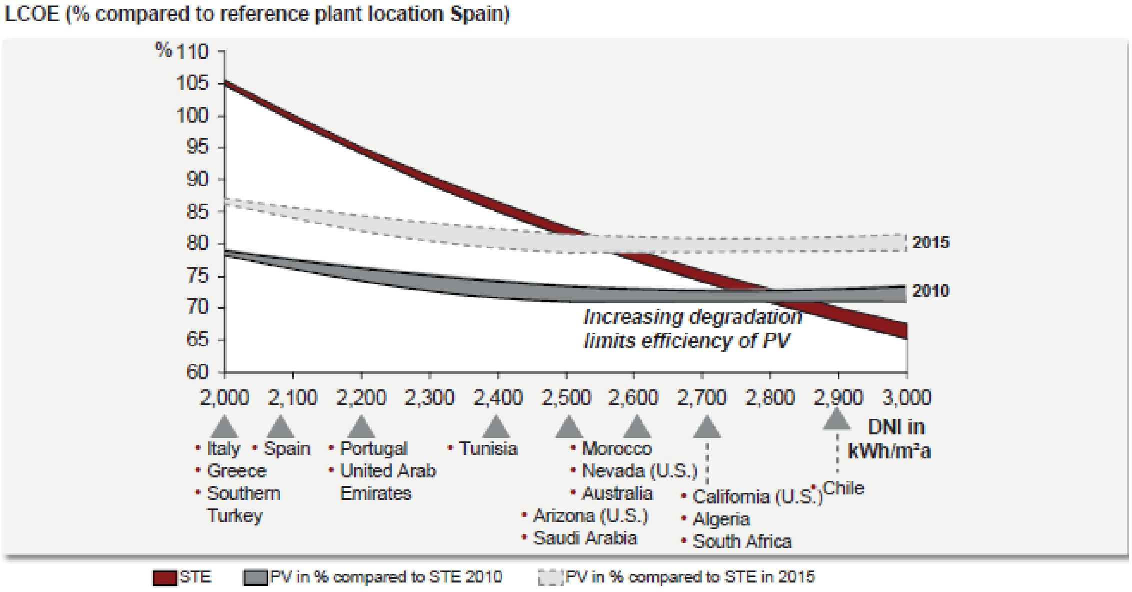
As it is shown in figure.6, although the STE is not still competitive with other conventional energy sources, the forecasted LOCE for STE is expected to compete against them in the future (2025). In other words outcomes of this report forecast domination of this technology in the future.

Figure 6. LCOE comparison of STE Vs. Conventional sources



When compared with Photo Voltaic (PV), STE might appear at a slight cost disadvantage in regions of medium irradiation. However, dispatchable and non-dispatchable STE technologies still provide some grid advantages that make it an alternative to consider. Due to fluids operating temperatures which do not cool down immediately as a result of transient clouds (fly wheel effect), STE plants can continue to operate in such conditions (the same does not hold true for PV systems). On the other hand, as you can see in figure.7 in areas of high irradiation (insolation) STE is expected to be competitive against PV. It means that, STE plant's efficiency increases in location with higher direct normal insolation (DNI) levels. For instance if we compare Italy with 2000 DNI in kWh/m²a and Algeria with 2700 DNI in kWh/m²a, LCOE percentage would decrease from 105% to 75%. This shows the higher efficiency of these systems in geographical areas with higher DNI.

Figure 7 Levelised Cost of Electricity (LCE) comparison for Photovoltaic and Solar thermal energy



1.1.3 Conclusions from available articles and reports

In order to offer an account on the state of the topic regarding comparative unit costs for CSP technologies, we summarise in the following table 24 the more relevant economic data and conclusions from the papers and reports reviewd in the two previous points. As it is shown in this table different parameters are considered to make comparison among the available studies and projects. Selected parameters are chosen regarding to their importance in techno-economical evaluation of projects and studies. These parameters consist of: technology (parabolic trough or Dish Stirling), levelised electricity cost (LEC), land requirement (m2/kW), region and country, year, capacity of project, investment cost (US dollar or Euro), carbon emission level and O&M Costs. Although all of these data were not available about all projects bust these parameters are the most commonly used ones in available studies and reports.

1) About the type of technology Parabolic Trough projects are more popular than Dish-Stirling. It is expectable because of novelty of Dish-Stirling technology at its limited commercial application. Moreover, the other limitation of this technology is related to its lower capacity in comparison with parabolic trough method.

2) Geographical location of these projects shows that these projects are mostly carried out in Mediterranean area (about 7 projects) and other projects implemented in USA, Brazil and India. Since this technology is more developing particularly in emerging economies and also countries with insolation advantage, we expect further development of it in other geographical locations with more solar radiation efficiency.

3) On the other hand, CSP technologies are still capital intensive and the levelised cost of electricity (LCE) is currently high (Parabolic Trough = 0.20-0.36/kWh, Dish-Stirling=4.0-6.0 cent/KWh) and operations and maintenance (O&M) costs are also relatively high in the range of USD 0.02 to USD 0.035/kWh. These drawbacks and limitation impede the further development of this technology.

4) However, by considering the chronological development of these technologies we can observe that the capacity of it increased from 20-30 MW plants to 100 MW plants. Moreover, the same pattern is discernible for other parameters like levelised electricity cost (LEC) and land requirement. Thus, these technologies are becoming more cost effective (for about 28% - 40% till 2025) and cost reduction opportunities will come from economics of scale, learning effects, R&D advancement, a more competitive supply chain, and improvement in the performance of the solar field, solar-to-electric efficiency and thermal energy storage system. So we can conclude that these technologies are gradually become more efficient and prove characteristics of a disruptive technology (IRENA report, 2012).

Table 24 : Summary of CSP studies and reports (*: future studies)

	Ecostar Road Map(2003)	Ecostar Road Map(2003)	Ecostar Road Map(2003)	SEGS projects (I-IX)	Corria et al.(2006)	Brand et al.(2012)	Caldes et al.(2009)	Poullikkas(2009)*	Beerbaum & Weinrebe(2000)*		Tsoutsos et al.(2003)*	Abbas et al. (2011)	Muller-Steinhagen& Trieb (2004) ,IEA (2010), Kaygusuz(2011)	
CSP Technology	Parabolic DSG	Parabolic trough	Dish Stirling	Parabolic Trough	Dish Stirling	Parabolic Trough	Parabolic Trough	Parabolic Trough	Parabolic trough	Dish Stirling	Stirling Dish	Dish Stirling	Parabolic Trough	Dish-Stirling
Name of Project	INDITEP	INDITEP	N/A	SEGS	N/A	N/A	N/A	N/A(Future Plant)	N/A(Future Plant)	N/A(Future Plant)	N/A(Future Plant)	N/A	N/A	N/A
Country and Location	Spain-Seville	Spain-Seville	Spain-Seville	USA-California	Brazil	Morocco and Algeria	Spain	Cyprus Island	India	India	Island of Crete	Algeria	N/A	N/A
Year	2003	2003	2003	1985-1991	2006	2010	2010	2009				2009	2010	2010
Capacity	47MW	50MW	50MW	324MW	200MW	(SM2)?	50MW	50MW	80MW	9.5MW	50MW	100MW	10-200MW	0,01-0,4MW
Minimum Land Area	1.6 km²(total)/ Length of single collector: 150 m	1.72 km²(total)/ Length of single collector: 150 m	1.4 km²(total)/ Length of single collector: 120.4 m	All Plants Total = 2810 (m2)	Not Specified	Not Specified	Not Specified	Not Specified	18 m2/kW	20 m2/kW	Dimension of Unit: W=168 cm, H=122 cm, L=183 cm	Total :900000 m2, Area : 87.7 m2 & Unit Diameter 10.57 m(for 25 MW unit)	6-8(m2 /MW ha)	8-12(m2 /MW ha)
Investment Costs	2840 €/kWel	3 530 €/kWel	8035 €/kWel	Not Specified	$1125–$3000(kW)	6090 (€/kW)	265,837k€	7680 US$/kW	2900 US$/kW	4700 US$/kW	Not Specified		2900(US$/kW)	2900(US$/kW)
Levelized Energy Cost	0.187 €/kWhel	0.172 €/kWhel	0.2811 €/kWhel	Not Specified	$0.070–$0.090(electricity cost/kWh)	Not Specified	Not Specified	7.12 US$/kWh	12.2 (cts/kWh)	15.8 (cts/kWh)	0.071 (€/kWh)	11.5, 18.5,23.5 ($/kWh)	5.6-9.1(cent/KWh)	4.0-6.0(cent/KWh)
O&M Costs	0.039 €/kWh	0.032 €/kWh	0.039 €/kWh	Not Specified	Not Specified	Not Specified	240,380 k€	Fix O&M: 4.16(US$/kW-month)/ Variable O&M: 0.7 US$/MWh	Not Specified	Not Specified	labour cost: 2.2.k€ and Consumables: 1.01 M€	Fixed 50 ($/kW-year) and Variable7 ($/MWh)	Not Specified	Not Specified

1.1.4 References

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1.2 Costs forecast for a scale-down DS model [9]

1.2.1. System cost estimation

Relatively some years ago, in the mid-80s, the first Dish Stirling System prototypes emerged. However, it still has not been introduced into the market because the price of DSS has not been reduced as expected into the 90s.

The few DSS which currently are into market still have a high cost, since their production is very limited yet and the demand of this product is also very low. Therefore there is shortage of producers and the supply on market is limited.

This section reflects the costs of the main components; in general the components which are more expensive are the solar collector or concentrator, the hub structure (which sometimes is included in the solar collector) and the Stirling engine. The following page**Error! No s'ha trobat l'origen de la referència.** shows the percentage which represents each part of the total cost of Dish Stirling System .

Percentage of installation reference [44]

Section	Component	Approximate Percentage	
Solar Field	Solar collector	14.5 %	18.8%
	Structure and supports	53.0 %	
	Solar tracking system	32.5 %	
Power Conversion Unit	Stirling Engine and Generator	80.7 %	52.4 %
	BOP	19.3 %	
Installation Cost	Mechanical assembly	33.8 %	9.0 %
	Mounting Solar System	20.1 %	
	Mounting Electric Components	39.5 %	
	Safety, arresters	6.6 %	
Infrastructure Cost	Electric infrastructure	80.7 %	7.2 %
	Assignment, connection grid	4.3 %	
	Adaption building	15.0 %	
Engineering		9.7 %	
Incidentals		2.9 %	

There are other components or accessories which are common to other solar systems and have more competitive prices. The following table shows a summary of DSS components cost which are found in the literature.

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[9] Based on working document 4.2.3.1 DS, Section 4.

Distribution of the compounds costs given by different references

Component	Cost
Solar collector (concentrator with structure)	3000 €/kW, [41], [43] 3200 €/kW , [28] 2300 €/kW , [45] 920 €/kW , [46]
Concentrator	550 €/kW0, [47]
Structure	700 €/kW , [47]
Receiver	170 €/kW , [41] 150 €/kW , [28] 190 €/kW , [43] 380 €/kW , [46]
Stirling Engine	415 €/kW , [41] 4170 €/kW ., [28] 380 €/kW , [43] 780 €/kW , [46]
Generator	60 €/kW , [28]
CollingSystem	38 €/kW, [28]
Balance of Plant	380 €/kW, [28]
Tracking System	270 € , [47]

Numbers between brackets [..] indicates the reference's paper or source from which the costs data have been drawn. See these references at the end of this point.

It is important to note that cost is not always proportional to kW, depending on the size of DSS the cost can be lower o higher. Approximately, a DSS with 10 m^2 can produce 1 kWe, which is the conversion factor used to change the data which was in €/m^2.

Some of the different costs are initially expressed in $. The change to € has been made in order to have a common unit and be able to properly compare them. The exchange rate used is 1.3$/€.

To better understand the different costs that every reference gives, it is important to know which kind of Stirling dish they describe:

In document [28]: This document has a table where it explains the model cost of the different parts of the Stirling system. It is important to know that it was written in 1997, so the costs have changed considerably since then. However, they also did a forecast of the different parts cost, which was too optimistic, as far as right now the total cost should be much more cheaper than it actually is.

In document[41]: It is a SAM program based model. In this case, the different costs include installation of the equipment, in order to have better idea about the real total cost. It also gives the possibility to add a contingency parameter which is used to add special costs such as solar field preparation, energy storage, unexpected costs, etc. They consider it a 7% of the total cost.

In document[43]: It describes a cogeneration system which could produce electricity and also thermal energy. This thermal energy is connected to a gas combustion chamber, making a hybrid system, in order to provide enough energy to a residential building. All the costs are also got from an economic model, not from a real project.

In document [45]: This document describes an economic viability study of a 10 MWe plant that uses thermal storage, exploring the possibility to use parabolic dishes or a single concentration tower. The big scale production gives them the possibility to reduce the standard costs.

In document [46]: It compares different solar energy technologies, giving a cost analysis of all of them. The given costs are related to a 50 kW Dish Stirling, which is a bigger scale than the other documents.

In document[47]: This document refers to a low cost dish concentrator. They have used recycled components in order to see which could be its minimum cost. However, they do not use it for a Dish Stirling, but for a steam generator. The important part of this reference is the detailed cost separation they do of the different system components.

In addition, apart from the fixed costs, there are the variable costs which depend on energy production. In general the solar plants do not consume fuel and do not have fuelling costs, however they have maintenance and operation costs. The operation and maintenance costs are not very high, as far as they basically consist on cleaning the mirrors and lubrication of the moving parts. These can be considered between 1 to 3% of the total cost. They are normally developed to have a life expectancy of 15-20 years, in order to be able to minimize the annual operation costs [9]. If a larger life cycle is desired, changing of spare parts of the Stirling motor should be considered, increasing its operation costs, because they would pass from almost null cost to a noticeable amount. Finally, it can be considered that the transport and installation costs are 2,000 € and 2,000 €, respectively for small devices (i.e. Trinium by Innova).

Finally, the following table shows the cost of the system for different cases. Note that most of the costs are provided from power plants projects and not for single installations, except in document [28]. In addition, the margins cost are smaller in big Dish Stirling Systems than in small DSS. Finally note also that the estimated unitary cost has an over cost of 40%.

Cost of System

Reference	Year	Characteristics	Nominal Power	Approximate cost	Estimated Unitary cost
Error! No s'ha trobat l'origen de la referència.	1997	Prototype	25 kWe	241,846 €	13,544 €/kW
0	2008	Large Power Plant	25 kWe	56,230 €	3,150 €/kW
0	2008	Large Power Plants	10 kWe	27,620 €	3,867 €/kW
0	2013	Estimated	4 kWe	19,623 €	6,868 €/kW
0	2013	Estimated	3.58 kWe	17,243 €	6,742€/kW
0	2013	Estimated	9.60 kWe	41,977 €	6,122€/kW
0	2013	Estimated	8 kWe	79,338 €	13,884 €/kW

0	2013	Estimated	3.8 kWe	18,423 €	6,787 €/kW
0	1999	Large Power Plant	50 kWe	150,308 €	4,208 €/kW
00	2013	Commercial product (Innova)	1 kWe	19,900 €	24,000 €/kW
00	2013	Commercial product (Infinia)	3.2 kWe	26,500 €	10,700 €/kW
0	2013	Prototype (El.Ma)	0.5 kWe	50,000 €	100,000 €/kW

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1.2.2. Available commercial options

In the present section it is discussed about the available commercial options. The following table shows the different possibilities on the market.

Different options on the market

Company	Power/unit	Diameter	Weight	Cost/unit	Estimated Cost per kW	Yield	Others
Innova (Trinum)	1 kWe 3 kWt	3.75 m	600 kg	19,900 €	24,000 €/kWe	13.8%el 41.4%th	-
Energon	1.5 kWe 4.5 kWt	3.75 m	450 kg	Not defined	Not defined	≈20 %el ≈55 %th	It is not available
Infinia	3.2 kWe	6 m	1,525 kg	26,500 €	10,700 €/kWe	≈ 30% el	It is not available individually, the minimum pack is composed by 64 units
United Sun Systems	25-30 kWe	11.73 m	6800 kg	Not specified	Not specified	≈ 30 %el	-
Ripasso Energy	30 kWe	Not specified	Not specified	Not specified	Not specified	≈ 30 %el	No more information was given as far as it was far too big for the project.
Cleanergy	11 kWe	Not specified	Not specified	Not specified	Not specified	Not specified	No more information was given
El.Ma.	0.5 kW	2.4 m	600 kg	≈50,000 €	100,000 €/kWe	Not specified	-

Infinia has what it would be a very good product for the project interests, but after a period when they tried to sell them separately, they decided to sell them only in 64 unit packs. This is the way they achieved a good selling price. Their units are focused for large thermal parks, but are not as heavy and as large as the United Sun System and Ripasso units. Therefore the installation on roofs is more viable. Anyway, they are not able to sell anymore products, as they stopped their production and selling as soon as they went on bankruptcy on September.

Companies as United Sun System and Ripasso energy are automatically discarded because their products are far too big. These companies are focused on selling large thermal parks, and also these are very heavy and large, therefore it is complicated the installation on roofs. However the units are quite efficient and are interesting for ground installations.

Energon is still in a very early developing phase of the product, so there is no possibility to buy and use them, yet.

El.Ma. is the first of the companies that has a product that fits with the project priorities. However, its low generation combined with its weight and high cost makes it to be in the fringe, far from the best option.

Cleanergy has an interesting product but they are not selling or giving information to anyone unless it is a big number of units offer.

The Trinum system from Innova is the one that it fits better with the project, at least by the moment. Less than 4 m of diameter, 1 kWe, the same weight as El.Ma and a much lower cost make it probably the best option. It is configured to also generate thermal energy, losing part of the electrical efficiency.

To sum up, the production of Stirling dishes that could fit in the project basis is still very small and it gets reduced to prototypes. From all the manufacturers studied, only three of them could be interesting for the initial purpose of the project: Trinum by Innova, the prototype from El.Ma and the Stirling unit from Cleanergy. The initial purpose was to generate electricity with a small Stirling dish, less than 10 kW, and which it could be integrated in public buildings, mainly on the roofs. Below are presented the mainly advantages and disadvantages of each Dish Stirling product that could fit Project's objectives:

The Trinum system from Innova:

- ☑ Small size, 3.75 m diameter
- ☑ It provides hot water at medium temperature (40 ºC - 60 ºC)
- ☑ Low weight
- ☒ High cost for kWe produced
- ☒ Low efficiency

The prototype system from Energon:

- ☑ Small size, approximately 3 m diameter
- ☑ It provides also hot water
- ☒ It is not available and there is no information about it.

The Dish system from El.Ma

- ☑ Small size, 2.4 m diameter
- ☑ Low weight
- ☒ High cost

1.2.3. Selecting best market-available DS options

After doing a deep market search we can conclude that there is just one option that fits enough within the project priorities. El.Ma is discarded because of its high cost and low production/weight relationship (comparision with Trinum made in the). Cleanergy is also discarded because they are not going to use their time nor sell any product to us because we would be small clients.

Consequently, the only real option we have is to use the Innova system called Trinum. Its stronger points are the following:

- **It can produce electric and thermal energy:** However it was not one of the scopes of the project, it is very useful to be able to cogenerate, as it can supply the different needs of a building by itself.
- **Small scale:** It is small enough to be installed almost everywhere. It is better to have it on the ground, because of safety, but it is adaptable. The other possibilities were too big in general.
- **Modularity:** As it is a small scale Dish Stirling, it can be installed together with others, choosing how many dishes will be installed depending on the energy needs of the whole system.

- **Economy:** Being a system in its initial development phase it is obvious that it will have a higher cost than the mature technologies, such as photovoltaic. However, comparing with the other prototypes, as the one from El.Ma, its cost is low. With the bigger scale products we cannot compare as far as we are not going to be able to buy them anyway.
- **Automatism:** Its completely automatic operation is a very important point. Nothing has to be done for its normal operation, as it is capable to switch itself on, track the sun and produce by itself.
- **Low maintenance:** As it is a completely automatic system, and the only part which could lead to problems is completely sealed and ready to work 15 years with no problems, the maintenance is very low. It is important to clean the mirrors within some months frequency, and to introduce grease in the tracking motors, but nothing else should be needed in a normal operation, at least regularly.
- **Commercial product:** It is the only small scale Dish Stirling which is already developed and it is a commercial product. This makes a big difference with the other prototypes, as it is tested in real conditions and can be sold easily and with more warranties.

Characteristics of selected products

	Innova – Trinum	El.Ma - Prototype
Power/Unit	1 kWe / 3 kWt	0.5 kWe
Diameter	3.75 m	2.4 m
Weight	600 Kg	600 Kg
Working Fluid	Helium	Not specified
Yield	13.8 % el. / 41.4 % th	Not specified
Material Cost	19,900 €	50,000 €
Transport Cost	2,000 €	2,000 €
Installation Cost	2,500 €	2,500 €
Legalization/Project Cost	1,500 €	1,500 €
Maintenance	800 €/year	800 €/year
Total Cost	26,700 €	56,800 €

Note that the Trinum is larger and has more external components such as the cooling and control systems than ElMa's prototype, in which everything is integrated in the same dish system. Also is considered that the cost of maintenance is 800€ each year.

1.2.4. Cost forecast, per kWh, for a INNOVA-TRINUM's Dish Stirling pilot

(a) Placement, Barcelona area; roof top application, optimally oriented.

		%		
	Reference-power system (kWp)		3 kWthermal 1 kWelectric	
	Solar field surface		$11m^2$	
(1)	Dish Stirling System (provider package)	51%	19.000 €	
	Solar field: concentrator, tracking syt., structure			
	Power block: receiver, stirling engine, alternator			
	Electric control unit: engine and tracking controls			
	Hydraulic control syst.: energy management and safety			
(2)	Balance of System (BOS):	21%	10.520 €	
	Power block / Cooling System: hydraulic system		4.120 €	
	Control and Management: Electric control board		1.900 €	
	Support System components: foundations		2.000 €	
	Transportation (Barcelona area)		1.000 €	
(3)	Subtotal equipment cost for the system	=(1 +2)	28.020 €	
(4)	Installation + monitoring + legalization costs:	28%	10.590 €	
	Installation/ mounting		3.150 €	
	Monitoring system		4.800 €	
	Executive project, commissioning, and legalization & Administrative process (Barcelona area)		2.640 €	
(5)	Subtotal system Installations costs	=(4)	10.590 €	
(6)	**Total Initial Investment cost ,**	= (1)+(2)+(4)		**38.610 €**
(7)	Complementary investment (estimation each 12,5 years) #		2.990 €	
(8)	Initial Investment Cost, per W; = (12)/1000x(1)	10 €/W		
	Cost of the electricity generated			
(9)	System operating life (except for complementary investment)			25 years
(10)	Initial Investment annual amortization quota; linear			1.664 €
(11)	Financial cost (cost for interest, or, opportunity costs)			433 €
(12)	Annual maintenance costs			320 €
(13)	**Total system annualised costs,**	**= (10)+(11)+(12)**		**2.417 €**
(14)	Annual electricity thermal output (kWht) (*)			6.862 kWh
(15)	Annual electricity thermal output – eq. elect. (kWhe), A) ** ; = (14)/0,83			8.267 kWh
(16)	Annual electricity thermal output - eq. elect. (kWhe), B) ***; = (14)/2			3.431 kWh
(17)	Annual electricity output – stirling (kWhe) (*)			1.803 kWh
(18)	**A) Total system annual generation (**)**	**= (15)+(17)**		**10.070 kWh**

(19)	**B) Total system annual generation (***)**	**= (16)+(17)**	**5.234 kWh**
(20)	**A) Cost per kWh (**)**	= (13)/(18)	**0,24 €**
(21)	**B) Cost per kWh (***)**	= (13)/(19)	**0,46 €**

(#) *In is also equivalent to considered a cost of 2.990 € for components replacement throughout the system life span, 25 years.*

(*) *Netl output, deducting parasitic consumptions.*

(**) Approach ‘A)’: *In order to make the equivalence between thermal and electrical kWh, it has been considered a Joule effect – standard heating system, with a performance of 0,83.*

(***) Approach ‘B)’: *In order to make the equivalence between thermal and electrical kWh, it has been considered a heat pump system, with a COP of 2.*

Sensibility analysis (I): Unit-cost sensibility to **location,** (keeping the optimal positioning)

Barcelona (Spain)		**(e) Electric**	**(T) Thermal**		**total**	
			Thermal output	Thermal-electric (equiv.) A) X 0,83 B) X 2	**A)**	**B)**
	Annual Energy performance per kWp,	1.803,2 kWhe	6.862,9 kWht	A) 8.267,4 B) 3.431,0 kWhe eq	10.070,7 kWhe eq	5.234,3 kWhe eq
	Cost per kWh				0,24 €	0,46 €
Alexandria &Marsa-Matruh (Egypt)						
	Annual Energy performance per kWp,	1.942 kWhe	7.569,9 kWht	A) 9.120,3 B) 3.784,9 kWhe eq	11.062,3 kWhe eq	5.726,9 kWhe eq
	Cost per kWh				0,22 €	0,42 €
Chania (Greece)						
	Annual Energy performance per kWp,	1.798,5 kWhe	6.885,4 kWht	A) 8.295,7 B) 3.442,7 kWhe eq	10.094,2 kWhe eq	5.241,2 kWhe eq
	Cost per kWh				0,24 €	0,46 €
Al-Salt (Jordan)						
	Annual Energy performance per kWp,	1.711,5 kWhe	6.546,0 kWht	A) 7.886,8 B) 3.273,0 kWhe eq	9.598,3 kWhe eq	4.984,5 kWhe eq
	Cost per kWh				0,25 €	0,48 €
	Source: Performance ratios based on information provided by INNOVA.					

2 COST STUDY FOR SOLAR-COOLING *(SCH)* SYSTEM FED BY A *PT* UNIT AS SUN-COLLECTOR

2.1 An overview of available economic studies on SCH at international level

2.1.1. SCH Technologies: Terminology and cost elements

Solar-cooling technology is among the more promising of the renewable-energy options. Or, more precisely***, solar-colling-and-heating***, since warm water results as a by-product of that technology, which may then be driven to the thermal water circuit of the corresponding building –in summer time; or the system's sun field (collector subsystem) my be right away connected to the heating circuit –in winter time.

Contrary to the conventional cooling and heating systems with high level of energy consumption, it is environmentally friendly and it contributes to energy consumption reduction and significant decrease of CO2 emissions. In recent years, this field has experienced growth in new fields such as food preservation and process industries as well as air conditioning and it shows the importance and progress of this technologies.

In order to get an overview of the economic aspects of these technologies and their potential for further development, firstly we review here the available technical-economic literature on the topic.

Different solar-cooling technologies

Solar cooling and heating systems according to several characteristics are categorized in many different groups with many options as storage system or collectors. The first classification of these technologies suggested by Chan, Riffat, & Zhu (2010) put these technologies in two groups: active solar and passive solar technologies. Although passive solar heating and cooling technologies are important in building design and architecture of construction, in this study we focus on active system due to its relevance to renewable energies and solar heating and cooling technologies as domain of this study.

In active system, solar cooling technologies are generally categorized in two groups: closed and open cycles. The closed-cycle system is based mainly on absorption and adsorption cycles. This system normally consists of a heat engine driving a heat pump. Single-effect absorption system is the simple example of these systems that has been used widely in other projects. Solid and liquid desiccant cycles represent the open cycle. A part from these two groups, thermo-mechanical system is also developing as new type of technology in solar cooling market (Hwang et al., 2011).

Absorption and adsorption are two types of closed sorption systems. Desiccant cooling systems are open sorption systems.

Absorption systems .- Recent comparative study about various cooling system technologies proves the feasibility of only two technologies: solar electric compression refrigeration and solar absorption refrigeration. Solar absorption system is one of the most desirable and commercially developed systems. It is also cost-effective and feasible technology. This system accounts for 59% of existing units in Europe (Balaras et al., 2007).

Available solar absorption chillers include: half-effect, single-effect, double-effect and triple-effect systems. Single-effect LiBr/H2O absorption chillers have the benefit of being powered by normal flat-plate or evacuated tubular solar collectors. Consequently, the most of solar cooling systems are based on single-effect LiBr/H2O absorption chillers. Under normal operation conditions, such machines need typically temperatures of the driving heat of 80–100 and achieve a coefficient of performance10 (COP) of about 0.7.

In addition to single-effect absorption chillers, double-effect absorption chillers are also available in the market. Different from the former, two generators working at different temperatures are operated in series, whereby the condenser heat of the refrigerant desorbed from the first generator is used to heat the second generator. Thereby a higher COP in the range of 1.1–1.2 is achieved. However, driving temperatures in the range of 140–160 are typically required to drive those chillers. As a result, high-temperature solar collectors such as parabolic trough solar collectors should be chosen in solar cooling systems based on double-effect absorption chillers. As for other types of absorption chillers, there are only a few theoretical research works about half-effect absorption chillers and two-stage absorption chillers powered by solar energy. However, the practical applications of such systems were hardly any reported (Zhai, Qu, Li, & Wang, 2011).

One of the sparse examples cases of double-effect solar cooling systems is installed in Carnegie Mellon University, USA. This system is working with 52 m2 of parabolic trough linear collector; 16 KW double-effect. It has a natural gas burner in its regenerator to provide heat when solar energy is insufficient. This is the only system of the kind has been successfully worked for more than one year. This system is designed for a single floor building with 245 m2 of net floor area and 3.1 m of average height. It is an open plan and sub-divided by partition walls and furniture in nine offices and one conference space. The building has horizontal shading on the east and west facades. Fig.3 shows the building cooling and heating loads estimated by the building model (Qu, Yin, & Archer, 2010).

For comparing and contrasting the performance of different types of solar cooling systems, Balaras et al.(2007) contrast the performance of existing installed multi-effect chillers in Europe. This study shows coefficient performance (COP) as a function of the solar heat supply temperature for typical

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[10] The coefficient of performance or COP of a heat pump is the ratio of the heating or cooling provided over the electrical energy consumed. The COP provides a measure of performance for heat pumps that is analogous to thermal efficiency for power cycles. Q is the heat supplied to or removed from the reservoir and W is the work consumed by the heat pump.

$$COP = \frac{Q}{W}$$

single, double and triple-effect chillers with the same component size and under the same operating conditions (the corresponding Carnot performance curve is also shown for comparison). The single-effect system gives best results in the temperature range 80–100 C; for a higher supply temperature, it is worth switching to a double effect system, up to about 160 , and then to a triple-effect.

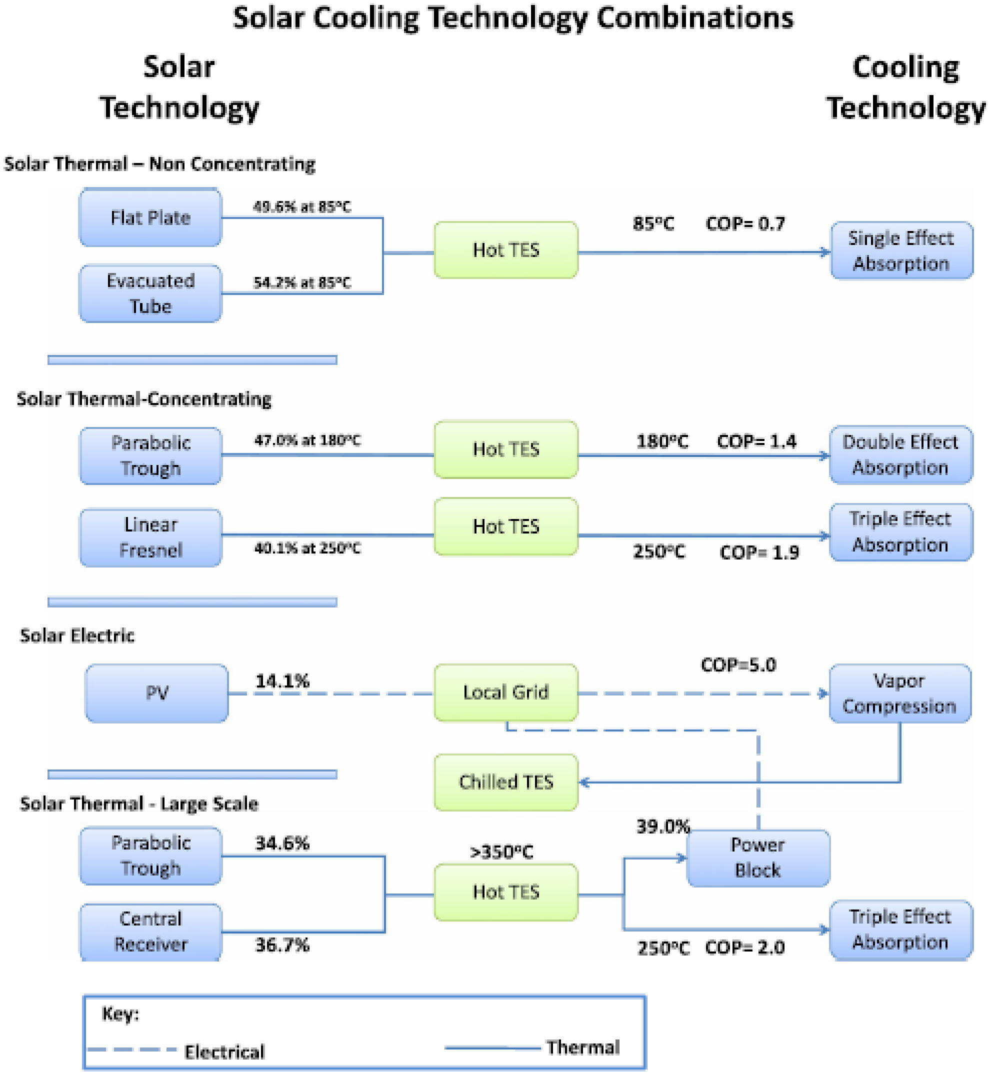
Other most promising solar-powered absorption cooling system is half-effect system. A two stage half-effect absorption refrigeration system consists of condenser, evaporator, two generators, two absorbers, two pumps, two solution heat exchangers, two solution reducing valves and a refrigerant expansion valve. Empirical studies about this system are not available yet but a simulation study by Kim and Infante Ferreira (2009) claim that this system is most favourable in terms of initial solar collector costs, excellent thermo dynamic properties of the working fluids and low driving temperature requirement. In addition, it provides effective operability in extremely hot weather conditions with very low risk of crystallization. The chillers considered in this condition are particularly suitable for air-cooled solar absorption cooling systems in hot and dry regions where a closed system is preferred due to the scarcity of water.

In general, absorption systems, particularly single-effect systems, are the most popular solar cooling systems in the market. Besides, half-effect, double-effect, and triple-effect systems need to develop further in order to be economically interesting in commercial market.

Adsorption systems, are other type of closes cycle systems working with solid sorption materials. In this system two or more adsorbers are needed to supply incessant operation. Adsorption systems require somewhat lower driving temperatures but have a relatively lower COP compared to absorption systems under the similar condition. Although this system have several promising advantages such as simple process, the wide range of heating temperatures and noiseless operation, further research and development work on small-size adsorption machines is essential to decrease their volume and raise the power density (Balaras et al., 2007).

Desiccant systems, is type of open-cycle system that employs water as the refrigerant in direct contact with air. The desiccant (sorbent) is used to help the exchange of sensible and latent heat of the conditioned air stream. It is called ‘open’ because the refrigerant is discarded from the system after providing the cooling effect and new refrigerant is replaced. Existing desiccant systems in the market use a solid sorption material such as silica gel. Despite of favorable features of these systems such as the possibility of pump and filter the desiccant, cool during absorption and heat during desorption, the option of energy storage by means of concentrated hygroscopic solutions, and bacteria-static qualities, these systems need further development in the future (Balaras et al., 2007)

Solar Cooling Technology Combinations (Mokhtar et al.,2010)



Summary of solar cooling paths. Efficiency and COP values are average values shown for convenience; in simulation, these values are changing throughout the day. In addition these values are based on chosen commercially available products.
Hot TES = thermal energy storage (Hot TES between the solar field and the cooling equipment is possible for all solar cooling technologies except PV with Vapor Compression chillers since the direct output of PV is electricity.)
Chilled TES = Thermal storage of chilled water is also another option for all technologies
COP = Coefficient of Performance

The solar cooling machine works thanks to and with other components such as solar collectors and thermal storage systems. Performance of these components directly or indirectly affects the final efficiency of solar cooling system. As a result, when we are assessing these systems we need to include them to represent a complete overview of the system. Based upon these components and different cooling technologies we can define many combinations, therefore it would be difficult to assess all the possible options at the same time and it makes comparison of these systems difficult.

Solar collector subsystem

Different types of solar collectors have been used in solar cooling systems. Generally collectors are categorized as concentrating and non-concentrating collectors. Non –concentrating collectors are cheaper, but produce lower temperature sufficient only for less efficient single or half-effect absorption machines. Flat-plate collectors are the most used non-concentrating collectors

These collectors have been used in numerous projects such as CIESOL building in Spain (Almeria)(Rosiek & Batlles, 2009), and Tunisia (Balghouthi et al., 2008). For getting higher temperatures, anti-reflective coating, double glass, and vacuum tube collectors are employed in this type of collectors. Concentrating collectors make adequately high temperature to run efficient multi-effect absorption machines, but these collectors in certain cases need tracking system, which is more expensive and requires additional installations. Parabolic-trough, Dish-Stirling and Linear-Frensel are typical concentrated collectors. Among the available collectors in the market, parabolic-trough has been used in several projects, and Linear-Fresnel increasingly gaining attention, but Dish-Stirling have not used yet in solar cooling systems and it need further attention in future studies (Chidambaram et al., 2011)

Storage subsystem

Since the sun radiation is not available all the time, the optimum utilization of these systems is to the large extent dependent on the thermal storage units used. In order to take most advantage of the solar resource and control differences between the cooling/heating demand and solar radiation availability, thermal storage is necessary in the solar systems.

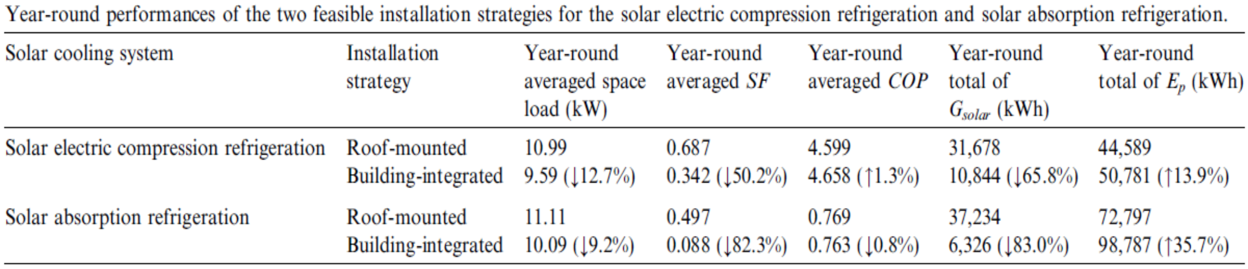
The available thermal storage systems in the market are: sensible, latent, and thermo chemical systems. Choosing between storage medium depends on the amount of energy to be stored, or the weight of the medium, and the temperature range at which it is required for a given application. The sensible heat storage (SHS) system consists of a storage medium, a container and input/output ports. Containers must retain the storage material and prevent loss of thermal energy. These systems use water, oil or pebble beds and it has very low heat capacity per unit volume. The performance of SHS systems is influenced by factors, such as the thermal capacity of the fluid used, the operating temperature range, the design and geometry of the inlet and outlet ports, the mixing introduced during the charge and discharge cycles, thermal losses from the storage device and the degree of thermal stratification in the storage device. (Chidambaram et al., 2011).

On the other hand, latent heat storage (LHTS or LHS) is based on heat absorption or release when a phase change material (PCM) undergoes a phase change. The latent heat storage by PCM in comparison with SHS contains a greater density of stored energy and functions in a narrower operational temperature range (Chidambaram et al., 2011). This storage unit is mostly suitable, because of its high-energy storage capacity, and its isothermal behaviour during the charging and discharging process.

2.1. 2. Available Studies and Reports

Comparing available cooling systems

In a comparative study of five types of solar cooling systems for a typical office in subtropical area (Hong Kong), Fong, Chow, Lee, Lin, and Chan (2010) have examined the performance of these systems with various possible combinations of installation strategy and solar collectors. These systems include solar electric compression refrigeration (solar electric cooling), solar mechanical compression refrigeration (solar thermal cooling): solar absorption refrigeration, solar adsorption refrigeration and solar solid desiccant cooling. They installed these systems in two positions: roof-mounted and building-integrated and these systems are tested with four different types of solar collectors: photovoltaic panels, flat-plate collectors, evacuated tubes and parabolic concentrated. Solar fraction (SF)[11], coefficient of performance (COF) and solar thermal Gain (G solar)[12] and Ep (Primary Energy Consumption) are used in this study to have a complete understanding of different aspects of the solar cooling system. Results of this study show that among these five systems, solar electric compression refrigeration and solar absorption refrigeration with evacuated tube or flat plate collector are the most feasible systems. The performance of these systems in sub-tropical weather condition is summarized below. The year round energy saving would be from 15.6% to 48.3% compared to conventional cooling systems.



Year-round performances of the two feasible installation strategies for the solar electric compression refrigeration and solar absorption refrigeration.

Solar cooling system	Installation strategy	Year-round averaged space load (kW)	Year-round averaged *SF*	Year-round averaged *COP*	Year-round total of G_{solar} (kWh)	Year-round total of E_p (kWh)
Solar electric compression refrigeration	Roof-mounted	10.99	0.687	4.599	31,678	44,589
	Building-integrated	9.59 (↓12.7%)	0.342 (↓50.2%)	4.658 (↑1.3%)	10,844 (↓65.8%)	50,781 (↑13.9%)
Solar absorption refrigeration	Roof-mounted	11.11	0.497	0.769	37,234	72,797
	Building-integrated	10.09 (↓9.2%)	0.088 (↓82.3%)	0.763 (↓0.8%)	6,326 (↓83.0%)	98,787 (↑35.7%)

In addition, the performance of this system with different type of collectors is reported in the article as follows

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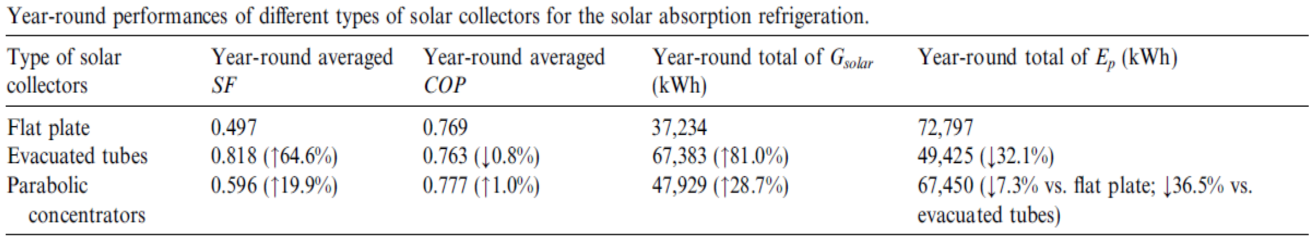
[11] Solar Fraction (SF) is the portion of solar energy contribution as compared to the total energy required to drive the refrigeration part of solar cooling system.

[12] Solar thermal gain is the useful energy acquired through the solar collectors to drive a solar cooling system. It is not just related to the efficiency of the solar collectors, but also the nature of energy demand of the solar cooling system.



Year-round performances of different types of solar collectors for the solar absorption refrigeration.

Type of solar collectors	Year-round averaged *SF*	Year-round averaged *COP*	Year-round total of G_{solar} (kWh)	Year-round total of E_p (kWh)
Flat plate	0.497	0.769	37,234	72,797
Evacuated tubes	0.818 (↑64.6%)	0.763 (↓0.8%)	67,383 (↑81.0%)	49,425 (↓32.1%)
Parabolic concentrators	0.596 (↑19.9%)	0.777 (↑1.0%)	47,929 (↑28.7%)	67,450 (↓7.3% vs. flat plate; ↓36.5% vs. evacuated tubes)

The framework and performance indicators of this study are certainly useful for our attempt of a comparative study of different solar cooling alternatives.

Efficiency evaluation of operating SCH systems

As mentioned before about the different types of cooling systems and their efficiency and performance, it is equally important to show economic evaluation of these systems. For more accurate evaluation, we need to consider the economic evaluation of these systems according to some criteria such as: thermo-economical evaluation, capital cost of systems, primary energy saving, solar fraction or Simple Pay Back (SPB) time. However, these indices have not been used commonly among the studies, and it makes it difficult to find a basis for comparison among them. In order to have a cost effective cooling system, we need to consider that the results of these studies are highly sensitive to the COP (co-efficient of the performance) and solar fraction (i.e. amount of energy provided by solar technology). In this part we focus on economic assessment and performance of most recent studies regarding various applications of solar cooling systems principally smaller size systems for public buildings, offices and housing sectors.

Recently, small scale application of solar cooling systems for residential and small office buildings is developing. Results of these studies show that small scale systems are still capital intensive and costly in comparison with conventional cooling systems and even the grid-coupled PV systems. In a comparative study for solar thermal and photovoltaic system in Spain and Germany, Hartmann et al.(2011) reported the annual cost of single-effect LiBr/Water cooling systems. The annual cost of solar thermal system is 128% and 134% compared to the grid-coupled PV system in Freiburg and Madrid respectively. The annual cost in Madrid is higher because of higher cooling demand during the hot seasons. More importantly, land area requirement for solar systems is six times larger than PV modules. Result of this study shows that in the solar thermal system for achieving 36% primary energy saving they need 160 m2 collector area while it is only 24 m2 for PV modules systems. Therefore, photovoltaic systems because of mature market and mass production outperform the solar thermal system.

Public buildings because of higher level of energy consumption and the larger scale of systems have always been considered for implementing solar heating and cooling (SHC) systems. In a study by Calise (2010), three types of university buildings in three different climate zones, (Milan, Naples and Trapani) in Italy are investigated to install SHC systems. This system is a single-effect LiBr-H2O absorption chiller which employed evacuated tube solar collectors. For calculating the economic performance of the systems they have used Simple Pay Back (SPB) method as the ratio between the extra capital cost and annual saving. Results of this study shows the system under investigation achieved a significant primary energy saving of 64.7%. It also suggests that economic profitability of SHC system could be improved in case of well-insulated buildings in Mediterranean climate. Moreover, compare to Naples and Trapani, the lower level of irradiation in Milan makes it less attractive because of longer SPB period for more than 18 years, by taking into account public contribution as feed-in tariff.

In comparison with conventional cooling system, a study in Spain (Hidalgo, Aumente, Millán, Neumann, & Mangual, 2008) reports the performance of a single-effect solar absorption cooling systems in housing air-conditioning. Results of this study shows that in terms of total expenses solar cooling systems achieve 62% energy cost reduction. In addition, CO2 emission from these systems is 36% less than conventional AC systems. However, the investment cost of these systems is much higher than conventional systems. This shows these systems needs further development in order to take advantage of economies of scale in manufacturing, marketing and distribution (Hidalgo et al., 2008).

In another study by Mammoli et al.(2010) about an installed system single-effect absorption system in New Mexico university, they have examined the performance of Heating, Ventilating, and Air-conditioning (HVAC) system in summer and winter. Although the performance of this system during winter is acceptable, in summer time this system does not demonstrate acceptable performance. Final results of this study show that installation of HVAC system can save about 20 USD/Day while a daily energy cost saving between 54 and 71 USD will be needed for the system to be economically feasible. Reasons for these discouraging results are: low energy cost in New Mexico State in USA and low performance of this system. Based on this study, with energy cost larger than USD 0.20/kWh this system is viable in some European countries. They recommend using solar cooling system after all the energy efficiency measurements applied in the buildings.

In a comparative study by Mateus and Oliveira (2009), they evaluated the feasibility of building-integrated solar absorption heating and cooling system. In this simulation by TRNSYS software, they evaluated the performance of solar heating and cooling systems in three different types of buildings and climates in Lisbon, Rome and Berlin (see table).

System size and efficiency of flat-plate collectors, for different solar fractions (values for heating plus cooling season)

Local building		Lisbon				Rome				Berlin			
Office building													
Solar fraction	Total (%)	20	40	60	80	20	40	60	80	20	40	60	80
	Cooling (%)	17	36	56	77	16	35	55	76	45	83	100	100
	Heating (%)	39	67	84	93	28	52	70	87	15	32	53	76
	DHW (%)	0	0	0	0	0	0	0	0	0	0	0	0
Size	Ac (m^2)	34	73	116	175	40	84	136	215	116	265	570	1005
	Vol (m^3)	3.1	6.6	10.4	15.8	3.6	7.6	12.2	19.4	10.4	23.9	51.3	90.5
Efficiency	Collectors (%)	28	26	24	22	30	27	25	22	21	17	12	9
Hotel													
Solar fraction	Total (%)	20	40	60	80	20	40	60	80	20	40	60	80
	Cooling (%)	9	32	54	77	11	33	57	79	32	68	93	100
	Heating (%)	9	40	60	81	9	33	53	74	6	21	43	71
	DHW (%)	97	99	100	100	97	99	99	99	90	93	95	97
Size	Ac (m^2)	64	165	295	495	78	206	372	625	230	590	1300	3000
	Vol (m^3)	1.9	5.0	8.9	14.9	2.3	6.2	11.2	18.8	6.9	17.7	39.0	90.0
Efficiency	Collectors (%)	34	28	25	21	32	27	23	19	20	15	11	6
Single-family house													
Solar fraction	Total (%)	20	40	60	80	20	40	60	80	20	40	60	80
	Cooling (%)	2	28	59	88	11	41	74	96	66	100	100	100
	Heating (%)	3	19	40	65	8	25	45	68	13	33	55	78
	DHW (%)	80	91	95	97	86	91	93	95	79	83	87	92
Size	Ac (m^2)	3	8	15	28	6	13	23	42	18	52	128	280
	Vol (m^3)	0.2	0.4	0.8	1.4	0.3	0.7	1.2	2.1	0.9	2.6	6.4	14.0
Efficiency	Collectors (%)	50	39	32	25	43	36	32	25	31	21	15	10

Efficiency of system with flat-plate collectors for different solar fraction

As it is shown in this table, they calculated the efficiency of solar heating and cooling system in these three cities with various solar fractions (20%,40%, 60% and 80%) . By considering the 20% solar fraction with flat-plate collectors, these systems are more efficient in Lisbon, Rome and Berlin respectively. Surprisingly, the efficiency of these collectors in single-family houses is more than hotels and office-buildings with larger scale of system.

The next table represents the costs calculated for each of the locations (for a system with an annual solar fraction of 60%): investment cost (including installation), energy, water and maintenance.

Costs of solar integrated system for the different locations and backup systems by item, for an annual solar fraction of 60%

Local	Collector type	Backup type	Investment solar (k€)	Investment backup (k€)	Electricity (1st year) (k€/year)	Gas (1st year) (k€/year)	Water (1st year) (k€/year)	Maintenance (1st year) (k€/year)
Lisbon	FP	Electrical compression	73	17	0.714	0.037	0.170	0.534
	FP	Gas	48	35	0.204	0.931	0.215	0.598
Rome	FP	Electrical compression	84	21	1.216	0.225	0.137	0.626
	FP	Gas	57	40	0.358	1.237	0.175	0.688
Berlin	VTC	Electrical compression	264	9	0.165	1.699	0.241	1.425
	VTC	Gas	244	22	0.164	1.716	0.238	1.445

To sum up, results of this study shows that, integrated solar system for heating and cooling save in total costs and CO2 emissions, particularly in South-European locations (Rome and Lisbon). Economic evaluation is preferable when natural gas is employed as system backup. Minimum costs depend on building type and location and the single-family house and the hotel have higher economic feasibility. With current energy costs, Rome is the only location where it is economically feasible. Vacuum tube collectors in comparison with flat –plate collectors allow us to reduce collector area between 15% and 50%. However, because of their initial cost, flat- plate collectors are more economically feasible. With annual solar fraction of 60% can only achieve a reduction between 35%

and 45% of exploitation costs, due to remarkable maintenance and water consumption costs. Even though the exploitation cost of a solar air-conditioning system is significantly lower in comparison with conventional cooling and heating system, the total cost (including investment cost, operation and maintenance costs) is truly high. In order to make these systems more competitive in the market, the authors recommend further reducing the initial costs for absorption chillers and solar collectors, by taking into account the existing costs of conventional energy sources such as gas, and electricity.

The only reported economic performance of Double-effect LiBr+ solar cooling plant is in Seville (Spain) with 174 kW cooling capacity (Bermejo, Pino, & Rosa, 2010). In this system they employed the linear concentrating Frensel collectors in 352 m2. As it is reported in this study the efficiency of collector[13] is between 0.35 and 0.4 and the average COP of system is 1.1-1.25. Results of this study put emphasize on the maintenance cost of Linear Frensel system, and their performance. Dirty mirrors in this system could reduce the performance of it to 50%. Nevertheless, the performance of this system is truly high and promising for further development. According to this report, solar heat fraction (SHF)[14] of this system is 0.75 and solar cooling ratio[15] is 0.44.

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[13] The sun tracking collectors' efficiency can be expressed as the ratio between net heat absorbed by the thermal-fluid (water) and the direct insolation on the solar field. It is a ratio of the solar direct radiation incident on the solar field (Q sun) and heat net gain (Qsc,a) of absorber tube.

[14] Solar heat fraction (SHF) that represents the heat injected into the absorption machine generator which is covered by the solar energy. Q solar = The total heat injected into the generator comes from the solar field, Q generator = total heat injected to absorption machine generator.

$$\mathrm{SHF} = \frac{Q_{solar}}{Q_{gen}}.$$

[15] Solar cooling ratio (SCR) that represents the efficiency of the complete system, as quotient between the useful cooling and the insolation on the solar field. Q evap = the cooling effect, Q sun = solar direct radiation incident on the solar field.

$$\mathrm{SCR} = \frac{Q_{evap}}{Q_{sun}}$$

A Summary of results and cost brake down (Mokhtar et al., 2010)

Technology	Capex ($/kW capacity)	CGC (¢/kWh)	CAPEX of CGC	Main of CGC	Solar/ Capex	Chiller/ Capex	TES/ Capex	Land/ Capex	Aux PV/ Capex	Excess energy ratio	Overall efficiency	Field size (m^2)
ETC A with A-1	8610	26.26	87.36%	12.64%	91.26%	3.90%	2.31%	2.50%	0.03%	44.87%	6.27%	45,380
ETC B with A-1	7681	23.41	87.41%	12.59%	90.22%	4.37%	2.59%	2.78%	0.04%	45.14%	6.41%	45,120
FPC A with A-1	4262	12.91	87.98%	12.02%	80.60%	7.87%	4.67%	6.78%	0.07%	46.68%	4.51%	61,000
FPC B with A-1	6946	21.16	87.47%	12.53%	89.02%	4.83%	2.87%	3.24%	0.04%	46.70%	5.99%	47,470
Parabolic A with A-2	3232	9.52	90.48%	9.52%	59.95%	22.66%	15.40%	1.99%	0.00%	34.31%	25.57%	13,600
Parabolic B with A-2	3672	10.81	90.50%	9.50%	65.07%	19.95%	13.55%	1.43%	0.00%	35.09%	32.51%	11,040
Fresnel A with A-3	8574	26.11	87.48%	12.52%	90.64%	3.58%	3.32%	2.37%	0.08%	51.59%	11.38%	31,480
Fresnel B with A-3	10,824	32.99	87.43%	12.57%	92.10%	2.84%	2.63%	2.37%	0.07%	51.59%	9.03%	31,550
Fresnel C with A-3	1581	4.74	88.92%	11.08%	59.58%	17.63%	17.99%	3.91%	0.90%	30.26%	24.25%	13,250
Thin film PV with VC	3912	11.88	87.71%	12.29%	83.94%	7.13%	7.27%	1.30%	0.36%	30.27%	29.41%	12,360
Multicrystalline PV with VC	2560	7.73	88.20%	11.80%	74.68%	10.89%	11.11%	2.76%	0.56%	30.25%	21.18%	16,160
Thin film PV with VC(GridCon)	3297	10.29	85.33%	14.67%	77.06%	8.89%	8.63%	5.42%	0.00%	39.15%	10.03%	18,610
Multicrystalline PV with VC(GridCon)	2801	8.43	88.53%	11.47%	73.15%	9.95%	10.15%	6.24%	0.51%	30.25%	8.57%	18,190
SEGS VI Elec with VC	1675	5.12	87.15%	12.85%	56.21%	17.49%	19.02%	7.28%	0.00%	39.15%	14.73%	12,680
SEGS VI Th with A-3	1726	5.14	89.50%	10.50%	56.69%	16.15%	18.45%	7.88%	0.83%	30.25%	11.01%	14,160
Parabolic 400 Elec with VC	2817	8.76	85.72%	14.28%	72.90%	10.40%	9.49%	7.21%	0.00%	39.14%	8.83%	14,920
Parabolic 400 Th with A-3	2790	8.39	88.64%	11.36%	72.14%	9.99%	9.58%	7.77%	0.51%	30.26%	6.91%	15,940
Tres Elec with VC	1528	4.67	87.09%	12.91%	54.95%	19.18%	14.15%	11.72%	0.00%	39.15%	10.02%	11,900
Tres Th with A-3	1624	4.84	89.48%	10.52%	55.54%	17.16%	13.31%	13.12%	0.88%	30.27%	7.03%	14,160
Tower200 Elec with VC	2295	6.79	90.09%	9.91%	84.43%	12.76%	0.00%	2.81%	0.00%	34.31%	25.57%	13,600
Tower200 Th with A-3	2735	8.08	90.19%	9.81%	87.37%	10.71%	0.00%	1.91%	0.00%	35.09%	32.51%	11,040
SEGS VI Elec with VC(GridCon)	3012	9.53	84.17%	15.83%	84.34%	9.72%	0.00%	5.94%	0.00%	39.15%	10.03%	18,610
Parabolic 400 Elec with VC(GridCon)	1356	4.27	84.60%	15.40%	69.41%	21.60%	0.00%	8.98%	0.00%	39.15%	14.73%	12,680
Tres Elec with VC(GridCon)	2550	8.04	84.45%	15.55%	80.55%	11.49%	0.00%	7.96%	0.00%	39.14%	8.83%	14,920
Tower200 Elec with VC(GridCon)	1311	4.10	85.27%	14.73%	64.01%	22.34%	0.00%	13.66%	0.00%	39.15%	10.02%	11,900

Improving cost/efficiency

As we discussed in previous parts, in order to increase the market penetration of solar cooling systems, we need to improve the economic performance of these systems. Several studies recommend new technologies or procedures to enhance the performance of these systems such as new fluid liquid, applying new type of collector with higher performance, or even some tips for optimal installation of systems among the others. With superior level of performance, we have a cost-effective and economically interesting cooling system..

As Mammoli et al. (2010) suggest, despite of low level of electricity consumption in absorption chiller systems, other ancillary electric devices such as glycol pump, tower pump and cooling tower fan are main reasons for electricity draws. Therefore, it is essential to consider the system optimization measures. For instance, glycol circulation pumping costs can be reduced by minimizing pressure losses in the solar loop, for example by installing collectors in parallel rather than in series (with correspondingly higher installation cost), or by increasing the heat medium temperature difference through the chiller (thereby slightly decreasing its efficiency). Cooling water demand in absorption chillers is generally much higher than in electric systems of the same capacity, and the higher flow rates can incur substantial pumping costs if piping is not sized appropriately. Moreover, many cooling towers are located several stories above the sump. Finally, cooling tower fans can also be substantial energy consumers, especially in the case of on–off control. At the end they recommend some design recommendations to optimize the performance of these systems. These recommended measures include: solar thermal collector array, hot water storage, cold water storage, absorption chiller, pumps and pumping the fluid flows, and air handling unit's improvement.

University of Zaragoza in collaboration with national renewable energy center(CENER) reported the performance of single-effect absorption cooling system (Monné et al., 2011). In this project they employed: flat-plate collectors in 37.7 m2, a 4.5 KW LiBr-H2O rotary absorption chiller and a dry cooler tower. By employing geothermal cooling system instead of initial heat rejection system, they achieved in improving the COP up to 42%.

New methods can also improve the performance of storage subsystem (Chidambaram et al., 2011). Based upon a comparative study between grid-coupled PV and solar thermal, Hartmann et al., (2011) demonstrate that stratified storage systems, instead of fully mixed storages, can reduce the cost of primary storage saving up to 150%**16**. In other study which is carried out in Almeria (Spain) a new internal storage system is examined (Sanjuan, Soutullo, & Heras, 2010).The main advantages of the system compare to liquid absorption systems are: smaller unit (absorption process and energy storage is combined in one), larger solar fraction, and higher adaptability of the system. However, it is not possible to substitute big absorption pumps because too many units would be necessary.

Despite of fairly similar thermal COP values of different collector subsystems, Hwang et al. (2011) recommend that mini-dish as advanced solar collector technologies provide new opportunities of achieving higher overall system efficiencies. This collectors assist the solar thermal system to out-perform the solar electric one. Gordon and Ng (2000) suggested two ways applying solar fiber-optic mini-dish concentrators. The first one uses solar heat from the mini-dishes to drive double-stage absorption chillers to achieve a COP of around 1.0. The second approach is the integration of the micro turbine driven by the higher temperature heat input from the mini-dishes, with the absorption cycle, which was then driven by the waste heat of the micro turbine. This configuration is possible since the heat rejection of the turbine was at around 360°C. This method can achieve the COP of about 1.4. They further suggested using the vapour compression cycle driven by the micro turbine to convert the energy of concentrated sunlight to the low- temperature latent heat storage (Hwang et al., 2011). Thus, research on the advanced solar collector to attain higher solar collecting efficiency is the most important research topic in addition to developing more efficient and more compact cooling systems.

According to Venegas et al. (2011) study about the single-effect solar cooling system with flat-plate collectors, wind velocity magnitude and direction is an important factor influence the performance of

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[16] With stratified storage, costs of saved primary energy decrease from 0.39 to 0.22 EUR/kWh for Freiburg in 2008 and from 0.30 to 0.17 EUR/kWh in 2015. In Madrid the costs drop from 0.32 to 0.17 EUR/kWh in 2008 and from 0.23 to 0.11 EUR/kWh in 2015.

cooling systems in Mediterranean weather condition. Results of this study show that wind effect is crucial reason in reducing the system performance up to 12%. Its negative effect could be reinforced when incidence angel approach the front side of the collectors (front impinging wind). Therefore, they suggest installing non-shadowing wind protection device in future facilities, particularly in windy location.

2.1.3 Conclusions from the reviewed articles and reports

Review of existing solar cooling technologies and performance of these systems shows that despite of wide range of technological development in this field, this industry is still young and economic performance of these systems require further improvement. In reviewed projects and studies, main restrictions in industry development are discussed in three parts: (1) technological performance improvement, (2) policy support, and (3) techno-economic assessment method. In previous parts we explained about all the possible technological options in terms of technical performance, capital costs and tips to improve the economic performance of them in great detail. Moreover, the policy supports such as feed-in tariff and energy cost are beyond the domain of this report and it needs to be considered in other study. Nevertheless, apart from aforementioned reasons, taking into account the previous studies demonstrate that possible drawback in solar heating and cooling development is assessment method of these systems.

Current state of the art in solar cooling literature shows that most of these studies have focused on technology performance (performance of given technology) instead of system performance (performance of unit-system). Consequently we observe that in most of these studies the efficiencies of cooling equipment and solar fields are sufficient and viable while in the practice these systems are working under estimated performance. Drawbacks of this evaluation mechanism shows that we need a comprehensive analysis to consider the cooling system in interaction with other components and fluctuation in weather condition.

A new method is suggested by Masdar Institute of Technology (Mokhtar et al., 2010) to assess various solar cooling technologies in consistent and standardized manner. In this new method other key factors such as: cooling demand time series, solar resource availability, weather condition, cost of components and performance parameters are included. In this study for a better comparative assessment of solar cooling systems, they proposed two new indices: Cooling Generation Cost (CGC) and Overall Efficiency (OE). CGC is defined as “the price-life-cycle cost, shown as net present value, paid for each kWh of cooling energy generated ” (Mokhtar et al., 2010; P.3767).17 OE

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[17] The costs included in this index are the costs of the solar field, cooling equipment, thermal storage, land, maintenance, installation and financing. In addition, this figure is based on the performance of each solar cooling technology and the demand time series. Cleaning of the solar field is not included in CGC as these costs are relatively small and comparable across the different technologies.

represent the "ration between the cooling output and the solar input(GHI[18]) on the total area of land consumed by the solar field" (Mokhtar et al., 2010; P.3767). Therefore, not only performance of whole system but also land utilization is considered in this index. According to this study a step-by-step assessment (see appendix.2) is suggested for comprehensive evaluation of cooling technologies. The first step is technical assessment of solar cooling systems. In this line, we identify the viable combination (see appendix.1) of solar cooling by taking into account the needs of the specific system. Each solar cooling technology is then evaluated independently; the solar field performance and cooling equipment is assessed according to weather conditions and on accessibility of solar resource. Then, we need to set the required solar load fraction (solar load fraction is the ratio between the net annual useful solar cooling output (kWh-o) and the total cooling demand (kWh-d)). Finally, we start an iterative process to find out the necessary solar field size by taking into consideration the following important parameters that influence the effective solar load fraction: (1) solar cooling output, (2) cooling demand time series, and (3) storage size. When we got the solar load fraction results, the obtained CGC and OE values are then used for a comparative study of all the evaluated solar cooling technologies.

By applying this method 25 feasible combinations of solar cooling technologies are compared based upon Abu Dhabi, UAE, climatic condition and cooling demand time series (see appendix.3). Outcomes of this study from the economical perspective confirm that large-scale cooling plant are the most viable option and in small-scale applications Fresnel concentrators and thin film PV cells are the most economically feasible collectors. From performance perspective multi-crystalline PV cells with vapour compression chillers are the most efficient option. In addition, relation between the cooling demand and solar resource availability is a major factor in determining the most suitable solar cooling technology for a certain location. This study concludes that in order to determine the most economical solar cooling option, two mainly significant parameters are the cost of the solar collection technologies and the performance of the refrigeration technologies. Therefore, for achieving significant reduction in investment costs of solar cooling technologies we need to select the most efficient cooling equipment.

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[18] GHI = Global horizontal irradiation

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2.2 Costs forecast for the PT-SCH systems designed for the Project [19]

2.2.1. System cost estimation

Four sub-sections are considered in order to establish the basis of the estimate of the costs, namely: cost percentages of reference power plant initial investment, solar field estimate costs, thermal fluid system and cooling system commercial prices obtained from manufactures or suppliers, installation costs, and finally, annual estimation costs for parts and materials maintenance.

Solar field estimate costs

On one hand, the research group has been able to obtain solar concentrating cost from some of its manufacturers. On the other hand, “Assessment of the local manufacturing potential for CSP projects in the MENA Region” (The World Bank [26]**Error! No s'ha trobat l'origen de la referència.**) provides estimate solar field components and installation costs for large concentrating solar power plants.

Reference costs of Solar Field installed have been taken as 290 €/m2. The research group has calculated the costs of the solar fields which costs are unknown by applying the 290€/m2 to the total area of solar field required, which has been calculated by applying 2.5 factor to the total aperture area of the solar field.

The following two tables (M and R) present the estimate cost of the solar fields given by manufacturers and the ones obtained from reference respectively

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[19] Based on working document 4.2.3.1 SC, Section 4.

Solar field estimate cost		**SOLAR NEXT**				**ABSORSISTEM**		**CMT-Clima (BROAD)**
		chillii ISC 10	**chillii STC 8**	**chillii STC 15**	**chillii WFC 18**	**YAZAKI WFC SC 5**	**ROBUR ACF 60 HW**	**BCT HZ 23**
CHROMASUN	MCT	23,140.00	16,020.00	30,260.00	30,260.00	30,260.00	30,260.00	24,920.00
INNOVA SOLAR	Turbocaldo	60,000.00	36,000.00	72,000.00	72,000.00	72,000.00	72,000.00	60,000.00
IT.COLLECT	IT.Collect	29,919.89	20,150.13	37,247.21	37,247.21	37,247.21	37,857.82	31,141.11
NEP SOLAR	Polytrough 1200	-						
SOLTIGUA	PTMx 18	47,000.00	29,000.00	47,000.00	47,000.00	47,000.00	47,000.00	47,000.00
	PTMx 24	-						
	PTMx 30	-						
TSC	CCStaR	50,000.00	50,000.00	75,000.00	75,000.00	75,000.00	75,000.00	50,000.00

Table M: Estimate costs of solar concentrating collectors from manufacturers

Solar field estimate cost		**SOLAR NEXT**				**ABSORSISTEM**		**CMT-Clima (BROAD)**
		chillii ISC 10	**chillii STC 8**	**chillii STC 15**	**chillii WFC 18**	**YAZAKI WFC SC 5**	**ROBUR ACF 60 HW**	**BCT HZ 23**
NEP SOLAR	Polytrough 1200	37,285.71	24,857.14	46,607.14	46,607.14	46,873.47	47,139.80	39,150.00
SOLITEM	PTC 1100	37,976.19	25,317.46	47,470.24	47,470.24	47,741.50	48,012.76	39,875.00
	PTC 1800	31,195.71	20,797.14	38,994.64	38,994.64	39,217.47	39,440.30	32,755.50
SOLTIGUA	PTMx 18	-						
	PTMx 24	41,428.04	27,618.69	51,785.05	51,785.05	52,080.96	52,376.88	43,499.44
	PTMx 30	40,482.73	26,988.48	50,603.41	50,603.41	50,892.57	51,181.73	42,506.86
SOPOGY	SopoNova	45,123.12	30,082.08	56,403.90	56,403.90	56,726.20	57,048.51	47,379.27
	SopoHelios	41,484.28	27,656.19	51,855.35	51,855.35	52,151.66	52,447.98	43,558.49
	SopoTitan	37,826.66	25,217.77	47,283.33	47,283.33	47,553.52	47,823.71	39,717.99
TSC	CCStaR	-						

Table R: Estimate costs of solar concentrating collectors from reference

Termal-fluid-system estimate costs

No official price for the thermal oil system has been yet found, as this depends on the executive project. The research group has considered, however, an estimate of the thermal fluid subsystem for each system.

For Solar Next Cooling kits it has been considered a budget of 5,000 € for the thermal fluid system, which is a low temperature system, since its cooling kit includes most of the hydraulic components required.

For YAZAKI WFC SC 5, it has been considered a budget of 15,000€ since the cooling system does not include any hydraulic component, and the total estimate cost should be very similar with the chillii WFC 18.

For ROBUR ACF 60 HW and BCT HZ 23, it has been considered a budget of 30,000€ since the system does not include any hydraulic component, and since the thermal fluid system requires high temperature equipment, it is expected to be more expensive than a low temperature system. Moreover, consultations to specialized companies suggest the budget previously indicated.

Cooling machines/kits estimate costs

The following table presents the estimate cost provided by SolarNext for some of their cooling kits, as well as, absorption chillers provided by Absorsistem. CMT-Clima (BROAD) supplies the BROAD Absorption chiller BCT HZ 23, which cost has been estimated.

Company	SOLAR NEXT				ABSORSISTEM		CMT-Clima (BROAD)
Product	chillii ISC 10	chillii STC 8	chillii STC 15	chillii WFC 18	YAZAKI WFC SC 5	ROBUR ACF 60 HW	BCT HZ 23
Type	Adsorption Single effect	Adsorption Single effect	Adsorption Single effect	Absorption Single effect	Absorption Single effect	Absorption Single effect	Absorption Double effect
Reference COP	0.5	0.6	0.6	0.7	0.7	0.7	1
Reference capacity (kW)	10	8	15	17.5	17.6	17.7	21
Cost (€)	**28,500**	**23,500**	**39,500**	**41,000**	**32,094**	**33,543**	40,000
Excluded	Storage tanks. Piping and electric accessories and installation.				Pumps and storage. Refrigeration tower, piping and electric accessories and installation. Controller and sensors.	Pumps and storage. Piping and electric accessories and installation. Controller and sensors.	N/A

Commercial costs of thermally driven chillers based cooling kits

Note 1: The cost values in bold has been obtained from suppliers / manufacturers.

Note 2: the chilli kits include: chillii® System controller and sensors, chillii® sorption chiller, dry re-cooling unit, hot water loading pump, re-cooling pump, mixing valves. Other components like storage tanks, solar thermal collectors are optional. Installation and piping is not included and will be done normally by a local installation company.

Installation estimate costs

It has been obtained the estimate specific installation cost (€/kWcool), and without VAT, since it is indicated a share of 17% for "Installation costs" from an overall system cost of 50,756.3 (without VAT).

The research group has estimated a 20% respect the total material cost of the system. With this value, installation costs estimates have been obtained for every system considered, and are shown in the following Table.

Installation estimate costs		**SOLAR NEXT**			**ABSORSISTEM**			**CMT-Clima (BROAD)**
		chillii ISC 10	**chillii STC 8**	**chillii STC 15**	**chillii WFC 18**	**YAZAKI WFC SC 5**	**ROBUR ACF 60 HW**	**BCT HZ 23**
CHROMASUN	MCT	11,328	8,904	14,952	15,252	15,471	18,761	18,984
INNOVA SOLAR	Turbocaldo	18,700	12,900	23,300	23,600	23,819	27,109	26,000
IT.COLLECT	IT.Collect	12,684	9,730	16,349	16,649	16,868	20,280	20,228
NEP SOLAR	Polytrough 1200	15,052	14,052	21,428	21,728	21,947	25,237	22,352
SOLITEM	PTC 1100	14,675	10,884	18,470	18,770	18,989	22,677	22,374
	PTC 1800	13,251	10,941	16,761	17,061	17,280	21,880	21,861
SOLTIGUA	PTMx 18	16,100	11,500	18,300	18,600	18,819	22,109	23,400
	PTMx 24	15,690	14,690	26,880	27,180	27,399	30,688	22,990
	PTMx 30	17,752	16,752	19,952	20,252	20,471	23,760	25,052
SOPOGY	SopoNova	16,324	11,825	20,274	20,574	20,793	24,958	23,624
	SopoHelios	15,598	11,261	20,022	20,322	20,541	23,831	22,898
	SopoTitan	15,014	12,351	18,877	19,177	19,396	22,686	22,314
TSC	CCStaR	16,700	15,700	23,900	24,200	24,419	27,709	24,000

Installation estimate costs of each cooling system with Turbocaldo based solar field

Maintenance costs estimate

The costs estimate for maintenance of the different system options for parabolic trough and Turbocaldo solar collector options are presented in the following table.

They have been obtained from the annual nominal values in **Error! No s'ha trobat l'origen de la referència.**. The sum of "Parts and materials" and "Staff" has been divided by the reference solar field area (500,000 m^2), in order to obtain an estimate cost €/m^2. Since this estimate cost corresponds to Solar Field maintenance, the research group has considered to suppose the same estimate cost for the solar field and cooling subsystem, which is to say, multiply by 2 the "Cost Solar Field mant." and taking into account the small facililty scale factor of 2, the result is 16 €/m^2, which has been multiplied by the minimum surface area of the respective system options, which has been obtained by multiplying by 2.5 the aperture area area of the solar field in order to obtain their respective total maintenance cost.

Maintenance estimate cost		SOLAR NEXT			ABSORSISTEM			CMT-Clima (BROAD)
		chillii ISC 10	chillii STC 8	chillii STC 15	chillii WFC 18	YAZAKI WFC SC 5	ROBUR ACF 60 HW	BCT HZ 23
CHROMASUN	MCT	2,168.24	1,501.09	2,835.40	2,835.40	2,835.40	2,835.40	2,335.03
INNOVA SOLAR	Turbocaldo	1,920.00	1,152.00	2,304.00	2,304.00	2,304.00	2,304.00	1,920.00
IT.COLLECT	IT.Collect	2,521.52	1,698.17	3,139.04	3,139.04	3,139.04	3,190.50	2,624.44
NEP SOLAR	Polytrough 1200	2,304.00	2,304.00	3,456.00	3,456.00	3,456.00	3,456.00	2,304.00
SOLITEM	PTC 1100	2,200.00	1,430.00	2,640.00	2,640.00	2,640.00	2,750.00	2,310.00
	PTC 1800	1,807.20	1,445.76	2,168.64	2,168.64	2,168.64	2,530.08	2,168.64
SOLTIGUA	PTMx 18	3,735.12	1,867.56	3,735.12	3,735.12	3,735.12	3,735.12	3,735.12
	PTMx 24	2,479.97	2,479.97	4,959.94	4,959.94	4,959.94	4,959.94	2,479.97
	PTMx 30	3,048.77	3,048.77	3,048.77	3,048.77	3,048.77	3,048.77	3,048.77
SOPOGY	SopoNova	2,654.98	1,689.53	3,137.71	3,137.71	3,137.71	3,379.07	2,654.98
	SopoHelios	2,454.50	1,534.06	3,068.12	3,068.12	3,068.12	3,068.12	2,454.50
	SopoTitan	2,293.60	1,834.88	2,752.32	2,752.32	2,752.32	2,752.32	2,293.60
TSC	CCStaR	3,452.80	3,452.80	5,179.20	5,179.20	5,179.20	5,179.20	3,452.80

Maintenance estimate costs

Overall PT-SCH system costs estimate

Table 32 presents a comparison of the most interesting system options in terms of sorption technology, chiller model, cooling capacity, as well as, solar field, power block, acquisition and installation costs, and, finally, ratio of €/kWe and performance of the cooling system.

In the tables presented below, bold type values correspond to information given by manufacturers or suppliers. The other data have been obtained from the explained reference documents and corresponding calculations.

As a summary, depending on the solar collector:

- Cooling systems with parabolic trough based solar field are more economical but present worse overall cooling performance. Moreover, their maintenance is more expensive since they require larger collector aperture area.
- Cooling systems with Turbocaldo based solar field are more expensive but present better overall cooling efficiency. Moreover, their maintenance is less expensive since they require less collector aperture area.
- Cooling systems with higher cooling capacity present a better ratio €/kWcool respect cooling systems with lower cooling capacity.
- High temperature cooling systems require special equipment and thus they are expected to be more expensive.
- Cooling systems requiring a refrigeration tower are expected to have a higher initial investment

Summary of estimate costs and performances of PT-SCH candidate systems

System comparison				Chiller Cooling Power (kW)	Solar Field estimate cost (€)	Thermal fluid system estimate cost (€)	Cooling kit estimate cost (€)	System acquisition cost (€)	Installation costs (€)	Maintenance cost (€/yr)	Ratio €/kW	System performance (%)[20]
SOLAR NEXT	chillii WFC 18	INNOVA SOLAR	Turbocaldo	**17.5**	72,000	5000	41,000	118,000	23,600	2,304	8091	30.5%
		SOLITEM	PTC 1800		39,307	5000	41,000	85,307	17,061	2,169	5850	33.1%
		SOLTIGUA	PTMx 18		47,000	5000	41,000	93,000	18,600	3,735	6377	28.8%
ABSORSISTEM	YAZAKI WFC SC 5	INNOVA SOLAR	Turbocaldo	**17.6**	72,000	15000	32,094	119,094	23,819	2,304	8120	30.5%
		SOLITEM	PTC 1800		39,307	15000	32,094	86,401	17,280	2,169	5891	33.1%
		SOLTIGUA	PTMx 18		47,000	15000	32,094	94,094	18,819	3,735	6416	28.8%
	ROBUR ACF 60 HW	INNOVA SOLAR	Turbocaldo	**17.7**	72,000	30000	33,543	135,543	27,109	2,304	9189	30.5%
		SOLITEM	PTC 1800		45,858	30000	33,543	109,401	21,880	2,530	7417	33.1%
		SOLTIGUA	PTMx 18		47,000	30000	33,543	110,543	22,109	3,735	7494	28.8%
CMT-Clima (BROAD)	BCT HZ 23	INNOVA SOLAR	Turbocaldo	**21**	60,000	30000	40,000	130,000	26,000	1,920	7429	43.5%
		SOLITEM	PTC 1800		39,307	30000	40,000	109,307	21,861	2,169	6246	47.3%
		SOLTIGUA	PTMx 18		47,000	30000	40,000	117,000	23,400	3,735	6686	41.2%
SOLAR NEXT	chillii STC 8	DIGESPO	DIGESPO	**8**	45000	40000	23,500	108,500	21,700	480	16275	9.5%

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[20] It has been applied a 0.7 IAM angle factor in order to estimate efficiencies of the discussed systems in Barcelona, except for two-axis sun tracking collectors such as Turbocaldo.

2.2.2. Commercial available options

In this section, is presented the different options available in order to implement a cooling system for rooftop (or courtyard) of public or private buildings. With this idea, estimations were carried out with the objective to identify which concentrating solar collectors were best depending on the global system efficiency. The ones with best global system efficiencies were chosen as candidates systems.

The table "Summary ..." that follows make explicit the characteristics of each system considered. They are candidates for the application considered.

- The candidates cooling systems are those which are absorption type chillers, namely: Chillii-WFC18, YAZAKI WFC SC 5, ROBUR ACF 60, BROAD BCT HZ 23.
- Three candidates for concentrating solar collectors have been chosen for their higher effectiveness, namely: INNOVA SOLAR "Turbocaldo", SOLITEM "PTC 1800" and SOLTIGUA PTMx Series.

For the DIGESPO system, the smallest sorption chiller ***"chillii STC 8***", and with lowest heat medium temperature required, was chosen since DIGESPO system cannot provide temperatures in the heat medium fluid higher than 45ºC. Indeed, the DIGESPO system is unable to provide enough temperature and output power for any cooling system considered in this document.

There are different ways to implement a cooling system by using solar energy.

Advantages and drawbacks according to the concentrating solar technology:

- Cooling systems with **Parabolic Trough** based solar field are more economical but present worse overall cooling performance. Moreover, their maintenance is more expensive since they require larger collector aperture area, however, they are lighter.
- Cooling systems with **Turbocaldo** parabolic dish based solar field are more expensive but present better overall cooling efficiency. Moreover, their maintenance is less expensive since they require less collector aperture area, however, they are heavier. **Finally, it is important to note that since the commercial Turbocaldo has a temperature limit of 110ºC nowadays it is incompatible with high temperature chillers such as ROBUR ACF 60 and BROAD BCT HZ 23.**
- Concentrating solar collectors are not recommended for low temperature applications such as to drive the Chillii-WFC18 and YAZAKI WFC SC 5 since flat plate collectors and evacuated tube collectors can accomplish similar performances. For this reason, ROBUR ACF 60 and BROAD BCT HZ 23 are recommended.
- Concentrating solar collectors can only use the Direct Normal Irradiance.

Advantages and drawbacks according to the sorption technology:

- Absorption cooling systems have higher efficiencies and cooling capacity but require higher temperatures. They are more expensive and, in general, they require a cooling tower such as Chillii-WFC18, YAZAKI WFC SC 5 and BROAD BCT HZ 23, which increases initial investment and maintenance costs. Continuous water supply is required. ROBUR ACF 60 it is an exception since it is cooled by air and can withstand high ambient temperatures, but as a drawback has higher electrical consumptions.
- Adsorption cooling systems have lower efficiencies and cooling capacity but require lower temperatures. They are cheaper and, in general, are cooled by air and water.
- Cooling systems with higher cooling capacity present a better ratio €/kWcool respect cooling systems with lower cooling capacity.

System comparison				Chiller Cooling Capacity (kWcool)	System acquisition cost (€)	Installation cost (€)	Maintenance cost (€/yr)	Ratio €/kWcool	Surface required (m2)	Estimated weight (kg)	System performance (%)
SOLAR NEXT	chillii WFC 18	INNOVA SOLAR	Turbocaldo	17.5	118,000	23,600	2,304	8,091	144	4,650	30.5%
		SOLITEM	PTC 1800		85,307	17,061	2,169	5,850	136	-	33.1%
		SOLTIGUA	PTMx 18		93,000	18,600	3,735	6,377	233	4,278	28.8%
ABSORSISTEM	YAZAKI WFC SC 5	INNOVA SOLAR	Turbocaldo	17.6	119,094	23,819	2,304	8,120	144	4,650	30.5%
		SOLITEM	PTC 1800		86,401	17,280	2,169	5,891	136	-	33.1%
		SOLTIGUA	PTMx 18		94,094	18,819	3,735	6,416	233	4,278	28.8%
	ROBUR ACF 60 HW	INNOVA SOLAR	Turbocaldo	17.7	Not technically viable						
		SOLITEM	PTC 1800		109,401	21,880	2,530	7,417	158	-	33.1%
		SOLTIGUA	PTMx 18		110,543	22,109	3,735	7,494	233	4,215	28.8%
CMT-Clima (BROAD)	BCT HZ 23	INNOVA SOLAR	Turbocaldo	21	Not technically viable						
		SOLITEM	PTC 1800		109,307	21,861	2,169	6,246	136	-	47.3%
		SOLTIGUA	PTMx 18		117,000	23,400	3,735	6,686	233	4,565	41.2%
SOLAR NEXT	Chillii STC 8	DIGESPO	DIGESPO	8	Almost not technically viable						

Summary of estimate costs and characteristics of the candidates systems

Advantages and drawbacks according to the implementation of a Solar Heating and Cooling system:

- Generation of domestic hot water and space heating and cooling is possible, and thus the combined overall efficiency is improved.
- It is expected the need to oversize the solar field in order to provide the overall heat demand (cooling and heating). It is expected higher initial investment for heat exchanger and heating distribution system (pump subsystem, piping and electrical accessories, controllers and sensors).

Advantages and drawbacks according to the implementation of a CHCP (Combined Heat, Cooling and Power) system:

- Generation of heat, cooling and power is possible, and thus the combined overall efficiency is improved.
- It is expected the need to oversize the solar field in order to provide the overall heat demand. It is expected a much higher initial investment.
- Both systems considered: DIGESPO and TRINUM, do not have the required thermal capacity in order to drive comfortably cooling systems. Back-up systems, like conventional boilers, would be required for correct operation of the CHCP system.

Advantages and drawbacks according to the implementation of a storage system:

- It is recommended to use thermal accumulators/buffers tanks in order to protect the heat source from fluctuations in the heat demand from heating systems, thus increasing the overall operating efficiency of the system. It also stores heat when it is available and delivers it when it is required. Thermal fluid system manufacturers could provide more information on this matter.

2.2.3. Selecting best Market-available PT-SCH options

The following solar concentrating collector manufacturers have not shown interest in this project and have been discarded: CHROMASUN, NEP SOLAR, SOLITEM, SOPOGY and THERMAX. And the following sorption chiller manufacturers have closed or haven't shown interest in this project: SHÜCO and CLIMATE WELL.

On one hand, the research centre considers that the adsorption chiller are suited for low temperature collectors such as evacuated tube collectors, for this reason it seems adequate to select chillers with higher heat medium temperature to optimize compatibility between concentrating solar collectors and the absorption chillers. For this reason the ***chillii WFC 18*** and ***YAZAKI WFC SC 5*** are discarded as viable options. The absorption chillers ***ROBUR ACF 60*** and ***BROAD BCT HZ 23*** are the viable candidates.

- The ***ROBUR ACF 60*** has as its main advantage that is cooled by air and no cooling circuit is required, that it withstands high temperature climates (up to 45ºC as ambient temperature), that has lower initial investment and maintenance costs. Its drawbacks are that yet this chiller operates at high temperature it is a single-effect absorption chiller with a COP of 0.7 and it has higher electrical consumptions.

- The ***BROAD BCT HZ 23*** has as its main advantages that it is a double-effect absorption chiller with a COP of 1 and its electrical consumptions are lower. Its drawbacks are that it is cooled by water, that it requires cooling circuit equipment and a continuous supply of water, that it has higher initial investment and maintenance costs.

On the other hand, the research group considers that the most interesting candidates for concentrating solar collectors are in first place: the ***SOLTIGUA PTMx Series,*** and in the second place: the ***IT.COLLECT Parabolic Trough Collector***. The first one for its high efficiency, lightweight and its economics; the second one for its architectural integration, and its inclined configuration capabilities which compensate the effect of Longitudinal Incidence Angle for one-axis tracking concentrating solar collectors.

Finally, the DIGESPO system is not able to heat thermal fluid of the cooling system over 50ºC and the overall thermal or cooling efficiency is low in comparison with other systems. For this reason, it is discarded as a viable option. The same can be said about the TRINUM based system.

An alternative to the previous candidates would be to a system with a low temperature chiller such as **YAZAKY SC 5** in combination with **Turbocaldo** based solar field.

*SUMMARY: System options candidates (*cost estimate)*

Cooling system	Absorption chillers	Company	ROBUR	BROAD
		Product	ROBUR ACF 60 HW	BCT HZ 23
	Dimension and weight	Depth (m)	1.23	-
		Width (m)	0.89	-
		Weight (kg)	370	649.674
	Sorption chiller	Type	Single effect	Double effect
		Reference COP	0.7	1
		Reference capacity (kW)	17.7	21
	Economics of the Cooling System	Cost (€)	33,500	40,000
		Excluded	Transport, piping and electric accesories and installation	N/A
Solar Concentrating system	Solar concentrating collector	Company	SOLTIGUA	
		Product	PTMx18	
		Units required	2	2
	Solar field	Estimated weight	3750	3750
		Net aperture area	82	
		Design temperature (ºC)	250	
		Peak reference efficiency	44.3%	
		Peak Reference capacity (kW)	30	

		Minimum required surface	206	
	Economics of the Solar Field	Cost (€)	47,000	47,000
		Excluded	Transport, installation, piping and electric accesories	
Thermal Fluid system	Economics	Cost (€)	30,000	
		Excluded	Installation and transport	
Additional costs	Installation (€)		22,109	23,400
	Maintenance (€/year)		3,735	3,735
	Transport (€)		5000	
	Legalization/Project (€)		5000	
Overall system performance		Overall system efficiency	28.8%	41.2%
		Chiller Thermal Input/Cooling capacity	25/17.8	21/21
Total cost (€)			142,609	150,400
Specific cost (€/kWt)			8,057	7,162

3 COST STUDY FOR BUILDING-INTEGRATED PHOTOVOLTAIC *(BIPV)*

3.1 BIPV costs: The state of the art (as from international data)

Photovoltaic is the most well developed solar technology around the world and it is a mature technology. Both, as plant-size facilities, and as decentralized, small size systems. However, there are still some applications of these technologies that need further market development. One of these applications is the PV technologies that, more than designed to be 'placed at' some spare surface in a building or facility, they are specific PV technologies intended for being integrated as part of a building or premise elements.

Thus, we can make use of sun radiation by different types of PV modules that, at the same time,may be integrated in façades, roofs and canopies as building envelope components.

The so called Building Integrated Photovoltaics (BIPV) inted to find a compromise between energy production and contruction characteristics such as sun protection, insulation and water tightness.

In this point we summarise our exploratory studies about costs and efficiency of the most spread BIPV technologies Then, in the following point (3.2) we focus on a cost forecast for the specific BIPV technologies that have been selected for being applied in the Project's actions in public buildings of the concerned Mediterranean Regions.

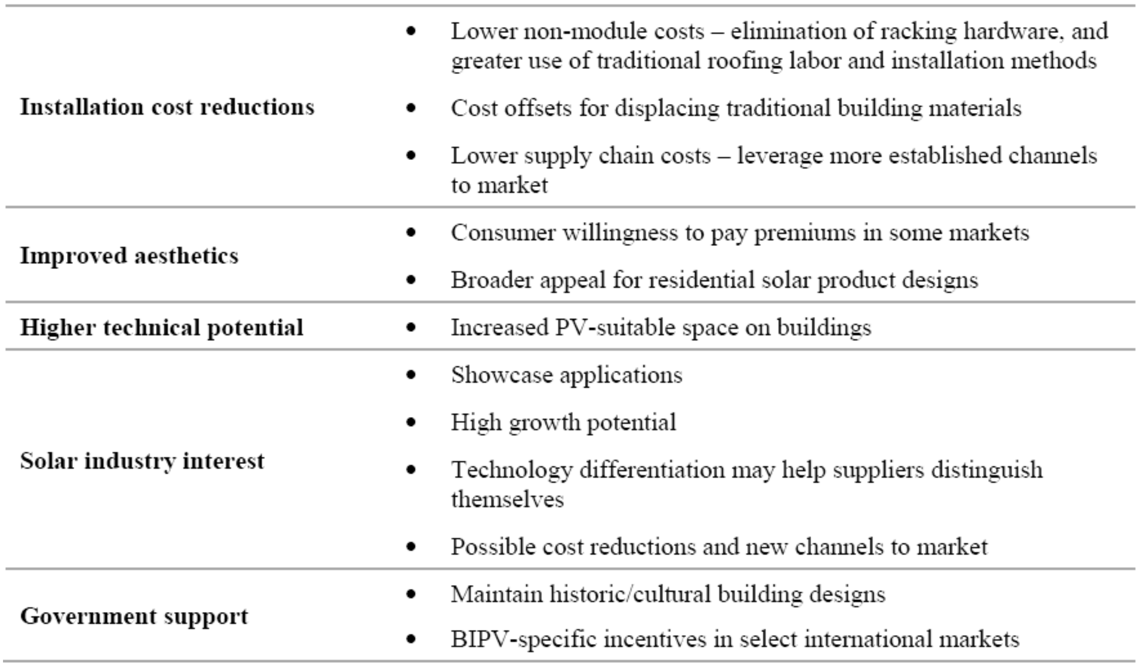
3.1.1 On the different BIPV technical options available in the market

BIPV modules vs. standard PV modules

Since 30 years ago there have been strong efforts to integrate PV modules with building materials. The first and easy solution was the rack-mounted photovoltaic. That is, the traditional PV systems that are designed to generate electricity only, mounted on racks and installed on the roofs, façade or shades of buildings. This first option, open–racked mounted system, is the least integrated one, and it is rather called 'rack mounted system'. The second option is rack mounted system more close, more integrated to the building. It is called "building applied PV" or "BAPV". Both applications use racking hardware and neither replace building material.

The third option is fully integrated PV system, in which the systems directly mount on the building and it is called building integrated PV or BIPV. According to the National Renewable Energy Laboratory (NREL), BIPV is defined as "a multifunctional product that generates electricity and replaces traditional building material by serving as significant weather barrier on building surfaces. Installation method is similar to the traditional building material" (James, Goodrich, Woodhouse, Margolis, & Ong, 2012)

In comparison with two other least integrated alternatives and BAPV, BIPV has several advantages. It replaces other building materials, sharing most of the installation and construcition principles, and does not require the mount rack hardware.



Installation cost reductions	• Lower non-module costs – elimination of racking hardware, and greater use of traditional roofing labor and installation methods • Cost offsets for displacing traditional building materials • Lower supply chain costs – leverage more established channels to market
Improved aesthetics	• Consumer willingness to pay premiums in some markets • Broader appeal for residential solar product designs
Higher technical potential	• Increased PV-suitable space on buildings
Solar industry interest	• Showcase applications • High growth potential • Technology differentiation may help suppliers distinguish themselves • Possible cost reductions and new channels to market
Government support	• Maintain historic/cultural building designs • BIPV-specific incentives in select international markets

Potential opportunities for BIPV (NREL, 2011)

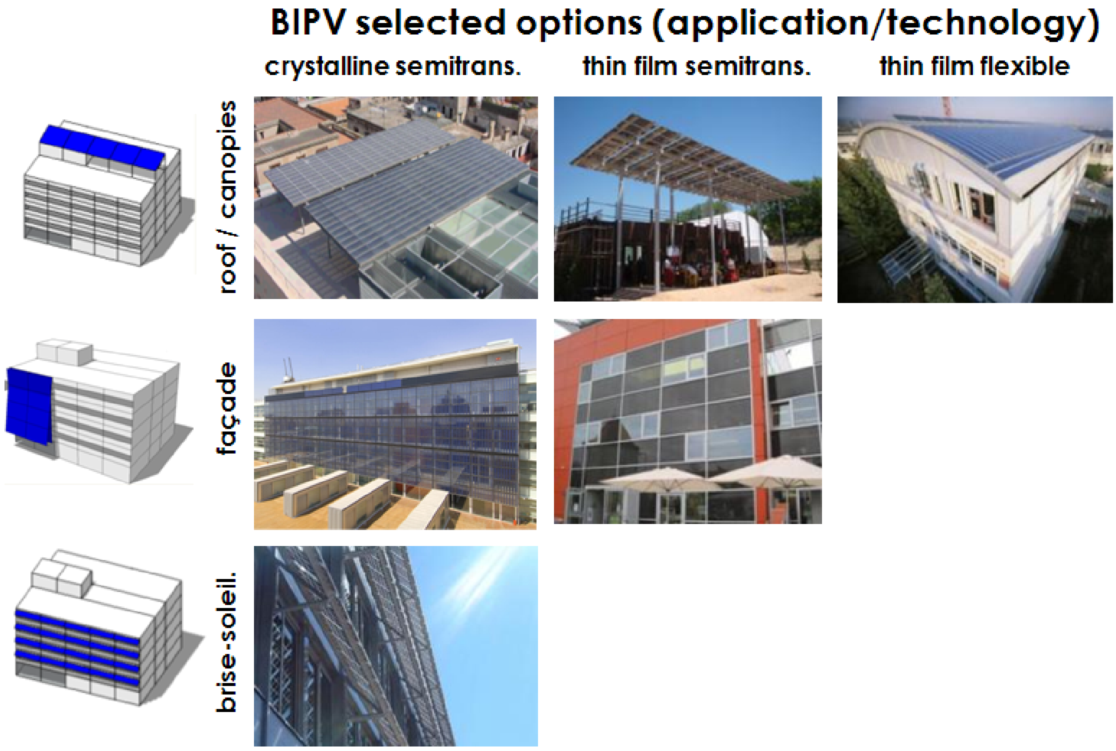
Solar panels or photosensitive sheets are the building blocks of a BIPV system. It means that PV modules specifications and designs determine the performance and cost of these BIPV. Therefore it is important to know about the different types of PV modules and the factors that determine performance and cost of these systems. Different types of PV modules with various prices and performances exist in the market. Among all the possible technologies, DIDSOLIT-PB project has focused its research and implementation in the following PV technologies for building integration:

BIPV-1: Semi-transparent, glass laminated, crystaline Silicon (approx. 30% transparency)

BIPV-2: Semi-transparent, glass laminated, thin film, a-Si (10-20% transparency)

BIPV-3: Opaque, plastic laminated, flexible thin film, a-Si (opaque)

According to the potential of the previous technologies and the building requirements



Even though nowadays the Crystalline technology is absolutely dominant in the PV market, due to its high efficiencies and production costs reductions, thin film technologies have an important market share.

The two ones above, have been taken into consideration due to their integration potential.

Except for high efficiency variants, thin film technologies offer less performance and therefore require almost double surface, compared to the crystalline ones, to harvest the same amount of power. However, besides its good performance with diffuse light and high ambient temperatures, they might offer some advantages in terms of building integration, specially in Mediterranean climate aeas:

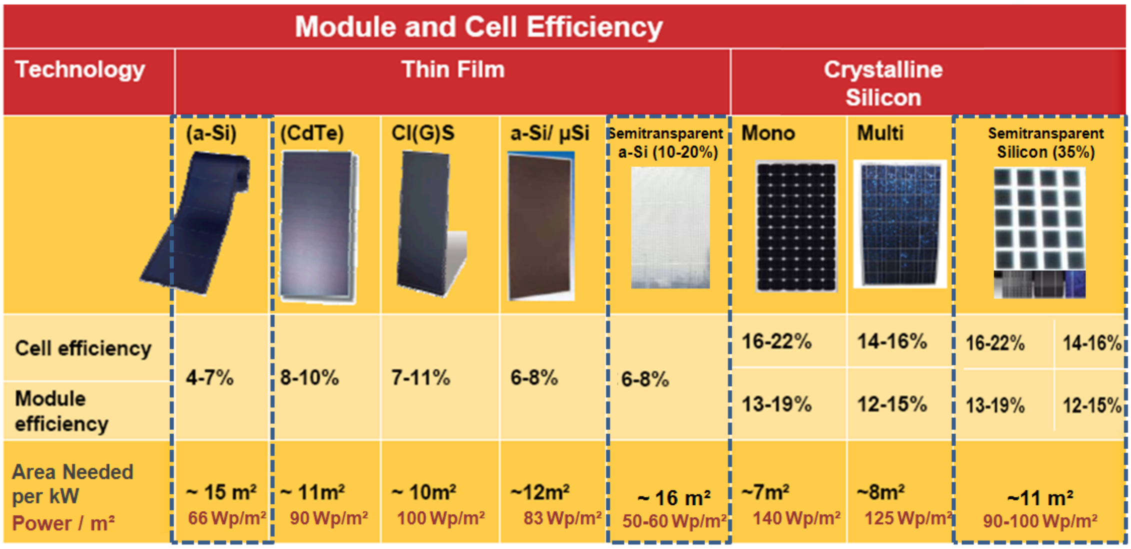
-Semi-transparent thin film has an extraordinary integration potential, in terms of visual and light properties.

-Flexible thin film provides lightness and ease of adaptation to metal roofs, with no substructure requirements, which reverts in lower costs and less environmental impact.

The las few years, thin film technologies have been suffering a strong loss of market share, mainly due to the more competitive prices of crystalline technologies and their lower efficiency (less installed power per sqm).

The flexible thin film have been seriously affected by the lack of providers. However, this light and flexible application, still presents some advantages and development potentialthat might be capitalized in the future, with new PV technologies such as organic or semi-organic cells.

Figure 1: PV technologies and DIDSOLIT options for building integration applications



Module and Cell Efficiency

Technology	Thin Film					Crystalline Silicon			
	(a-Si)	(CdTe)	CI(G)S	a-Si/ µSi	Semitransparent a-Si (10-20%)	Mono	Multi	Semitransparent Silicon (35%)	
Cell efficiency	4-7%	8-10%	7-11%	6-8%	6-8%	16-22%	14-16%	16-22%	14-16%
Module efficiency						13-19%	12-15%	13-19%	12-15%
Area Needed per kW	~ 15 m²	~ 11m²	~ 10m²	~12m²	~ 16 m²	~7m²	~8m²	~11 m²	
Power / m²	66 Wp/m²	90 Wp/m²	100 Wp/m²	83 Wp/m²	50-60 Wp/m²	140 Wp/m²	125 Wp/m²	90-100 Wp/m²	

Source based on EPIA 2010 , Photon International + own elaboration

Essentially, Building Integrated Photovoltaic (BIPV) refers to photovoltaic cells and modules which can be integrated into the building surface as part of the building structure, and therefore can replace conventional building materials, rather than being installed afterwards. BIPV modules can be naturally blended into the design of the building and form part of the building surface.

Figure 2: Examples of thin-film cells

The extra costs of BIPV might be compensated by their replacing other conventional products (roofing, facades and canopies) and by providing some of the same conventional properties, such as:

- Water-tightness (façade, roof, skylight, pergola)

  The water tightness comes not only from the glass properties, but especially from the mounting system that integrates it.

- Thermal insulation (façade, roof, skylight)

In most of the climates, building envelope glazing units have to fulfill certain insulation requirements. Glass laminated PV modules can be part of insulated glazing units that perform in the same way that a standard glaze should.

- Sun protection (façade, roof, skylight, pergola –roof / ground mounted-car sherter)
- Semitransparent surface (glazed surface: semi-transparency-solar factor; shading devices: brise-soleils, canopies, pergolas, etc)

There are some constructive properties that depend on the project specific requirements, and directly affect the PV module costs:

- Construction requirements: thermal insulation, semi-transparency
- **Size:**

  Depending on the project requirements, a certain degree of dimensional flexibility might be required. Standard dimensions might not be suitable in some cases.

  Thin film modules production process has strict rules regarding standard dimensions.

  Crystalline laminated modules have much more flexibility.
- **Glass composition and thickness:**

  The substructure system, its position in the building (façade, roof, etc) and modulation will determine the static loads and glass composition requirements.
- **Transparency**

  Building integrated solutions, might look for specific transparency rates.

  Depending on the sun protection and natural lighting requirements, the PV module transparency might range from 10% to 40%. Crystalline modules, due to the cell's composition, are much more flexible in terms of transparency options.

Crystalline silicon technology

Standard PV modules can be opaque or semitransparent. In *mono-* or *polycrystalline* modules, the spacing between cells and to the edge can be modified so as to allow variation of shadowing and transparency. In *thin-film modules*, additional cuts perpendicular to the cell strips create a semitransparent effect. Because semitransparent modules absorb less light, they are less efficient per unit of area. Therefore, performance diminishes with increasing transparency.

Depending on the sun protection and natural lighting requirements, the PV module transparency might range from 10% to 40%. Crystalline modules, due to the cell's composition, are much more flexible in terms of transparency options.

Standard crystalline silicon cells are made from thin slices cut from a single crystal of silicon (mono-crystalline) or from a block of silicon crystals (polycrystalline). Their efficiency ranges between 12% and 20%. It is the most common technology, representing about 90% of the current market.

Two main types of crystalline cells can be distinguished:

- Monocrystalline (Mono c-Si)
- Polycrystalline (or Multicrystalline) (multi c-Si)

The standard size is 6’ (156 mm), although 5’ and perforated cells are available in some cases.

Glass - laminated crystalline modules, technical parameters:

- Size: Depending on the project requirements, a certain degree of dimensional flexibility might be required. Standard dimensions might not be suitable in some cases. Global dimensions will depend on the lamination capacity of the provider and the modularity of the cells: Starting from 480 x 1475 mm; 720 x 1600 mm; 850 x 1650 mm; 1200 x 1800 mm, are typical optimized dimensions. However, the maximum available dimensions will depend on the glass lamination capacity of the manufacturer: 1600 x 2600 mm; 2100 x 3100 mm; etc.
- Glass thickness ranges from 4+4 to 6+6, depending on glass dimensions and static (snow, maintenance…) and dynamic loads (wind).
- Transparency: The distance between cells (about 1-2-4-6 cm, depending on the ribbons direction) will determine the PV module transparency (10-40%). The standard transparency, which is about 35%, leads to installed power ratios of approximately 90-100 Wp/m2.
- Junction box: Crystalline laminated modules can easily adapt both back and lateral junction boxes. Lateral junction box might be a good solution to hide all the cabling and connections inside the secondary substructure, such as aluminum or steel profiles and caps.

Thin film technology

Thin film modules are constructed by depositing extremely thin layers of photosensitive materials onto a low-cost backing such as glass, stainless steel or plastic.

Thin Film manufacturing processes result in lower production costs compared to the more material-intensive crystalline technology, a price advantage which is counterbalanced by lower efficiency rates (from 5% to 13%). However, this is an average value and all Thin Film technologies do not have the same efficiency.

Four types of thin film modules (depending on the active material used) are commercially available at the moment:

- Amorphous silicon (a-Si) (5-7%)
- Cadmium telluride (CdTe) (9-10%)
- Copper Indium/gallium Diselenide/disulphide (CIS, CIGS) (10-13%)
- Multi junction cells (a-Si/m-Si)

Although CdTe, CIS, CIGS modules might reach higher efficiency than a-Si ones, silicon has the advantage of being easily available in nature.

Thin film has better temperature coefficients of reduction in power output at higher temperatures, than crystalline modules.

Thin-film materials have better output in weak light than silicon modules. However, the global performance won't solely depend on the material, but also on the harmonization of the rest of the PV module characteristics.

Glass - laminated thin film modules, technical parameters:

- Size: Thin film modules production process has strict rules regarding standard dimensions.

  The manufacture process of the thin film modules is linked to a certain standard dimensions:

  Rigid CIS and CdTe standard modules are usually available in set dimensions of 600 x 1200. A-Si modules have a wider range of possible dimensions, although 600 x 1200mm; 1100 x 1300mm are the most common.

  The combination of these sub-modules and the subsequent lamination process enlarges the range of possibilities: 600 x 1200mm; 1245 x 635mm; 1242 x 1245mm; 2462 x 635 mm; 1849 x 1245 mm.

  Other dimensions are possible under request, increasing significantly the costs.

- Glass composition and thickness:

  Thin film modules have a particularity that comes from its production process: the a-Si film layer is deposited on a glass sub-base (3.2 mm float glass). In order to obtain the same characteristics of a 5+5mm PVB laminated glass, depending on the dimensions, sometimes it is required a composition of 6T+3.2+6T (T: tempered glass).

  This makes glass dimensional flexibility more difficult and costly.

- **Transparency**

  The transparency is given by the pattern cut made to the initial deposition.

  The resultant "microcells" allow a good visual transparency, even though the global PV module transparency percentage ranges are quite similar to the crystalline ones (10-30%).

  The standard transparency of 10% leads to installed power ratios of approximately 44 Wp/m^2.

  Opaque thin film modules can significantly increase the installed power ratios, till 66-110Wp/m^2, depending on the technology.

- **Junction box**

  Simple laminated thin film modules (not insulated ones) usually integrate small junction boxes (two: one for each pole) in order to simplify the module internal electrical interconnection.

  When the PV module requires glass lamination at both sides, the lateral junction box is also available, making the technical solution a bit more complex and costly.

Flexible cells

When the active material is deposited in a thin plastic, the cell can be flexible. This opens the range of applications, especially for Building integration (roofs-tiles) and end-consumer applications.

Flexible, ductile a-SI modules on high-grade steel strips, laminated in synthetic material (EFTE), currently have a width of approximately 40 cm and a length of up to 5-6 meters, which can be shortened on request.

3.1.2 Comparative costs of BIPV systems: estate of the art

The main components for any PV system are:

- Modules or photo-sensitive-material pieces
- Balance –of-the-system (BOS): Inverters, connections & cabling, monitoring devices, etc.
- Installation works
- Maintenance & Operating costs (O&M)

However, other factors like PV technology, size, and type of installation are also important to determine the total cost.

Most of the available studies and reports on PV systems' comparative cost correspond to the standard, rack-mounted, PV technology. Available information regarding BIPV is quite lesser. Thus, we first summarise the available data for standard PV technology's costs; and then will present the comparative few data on BIPV tehcnologies' costs.

Initial costs (Investment) for a *standard PV system*

IRENA's report suggest to comnsidere four PV systems in four end-use markets: (1) residential PV system (2) Large-scale building (3) utility-scale and (4) off-grid application. Since we are interested in public building PV system costs, total cost of residential PV system with less than 20 kW allow us to estimate a more accurate cost of these systems. According to this report in 2011 the average cost of residential PV system in Germany with capacity between 2kW and 5 kW is about USD 3777/kW.

Similar PV system cost in Spain, Portugal and Italy is about 5787/kW, which is close to United States with USD 5787/kW. For larger PV systems with capacity between the 5 kW and 10 kW the total installed cost decrease to USD 3600/kW in Germany, USD 5314/kW in Portugal and Italy and USD 5433/kW in United States(IRENA, 2012).

Price differences in various locations prove that project location and PV market competitiveness in each country is imperative factor in total PV installed price. For instance, in Germany because the PV market is more competitive than other countries the prices are significantly lower than other countries. Total PV system installed costs in various countries are illustrated in Figure.3.

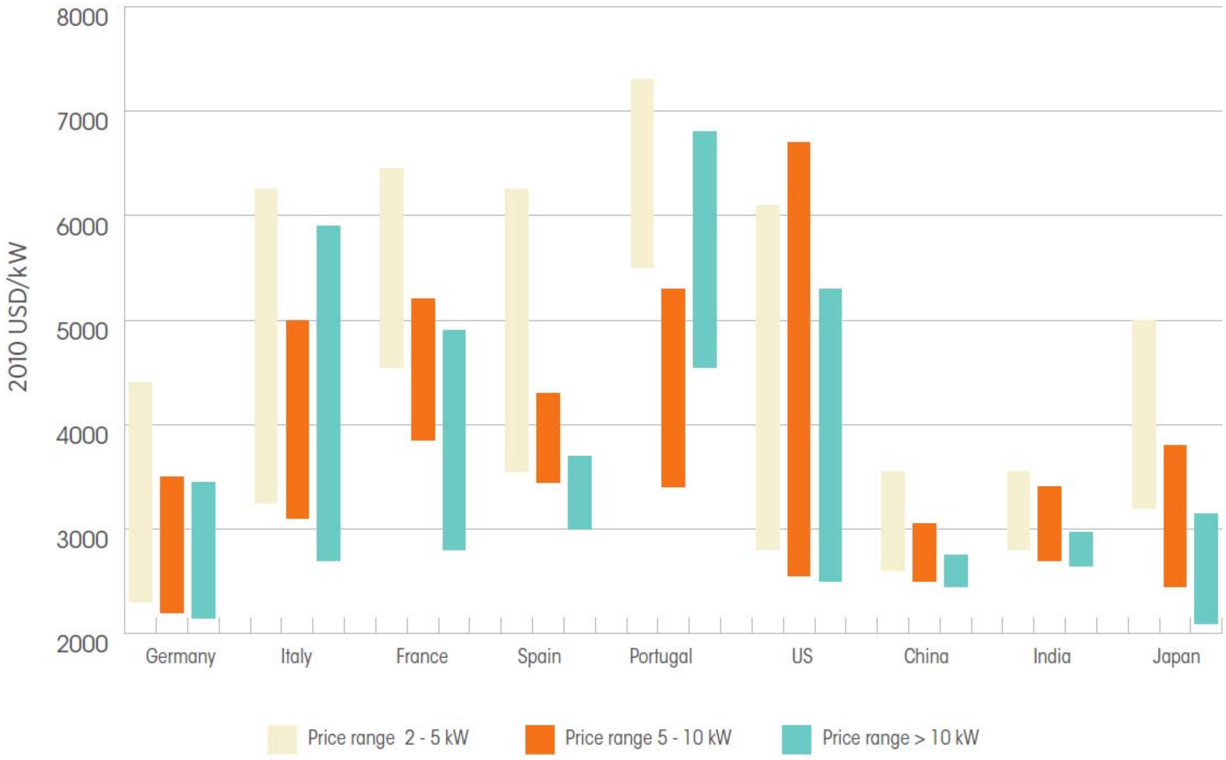


Figure 3. Installed PV system prices (Investment) for residential application in different countries (IRENA, 2012)

Latest report form Lawrence lab in Berkley (Tracking the Sun VI) reports PV installed price at six countries in Asia, North America, Europe and Australia. As it is shown in this report, latest installation costs for small systems (less than 5kW) is about USD 2.6/W in Germany, USD 3.1/W in Italy. This cost is significantly higher in Japan and United States with USD 5.9/W and USD 5.2/W respectively (See Figure 4) (Barbose, Darghouth, Weaver, & Wiser, 2013).

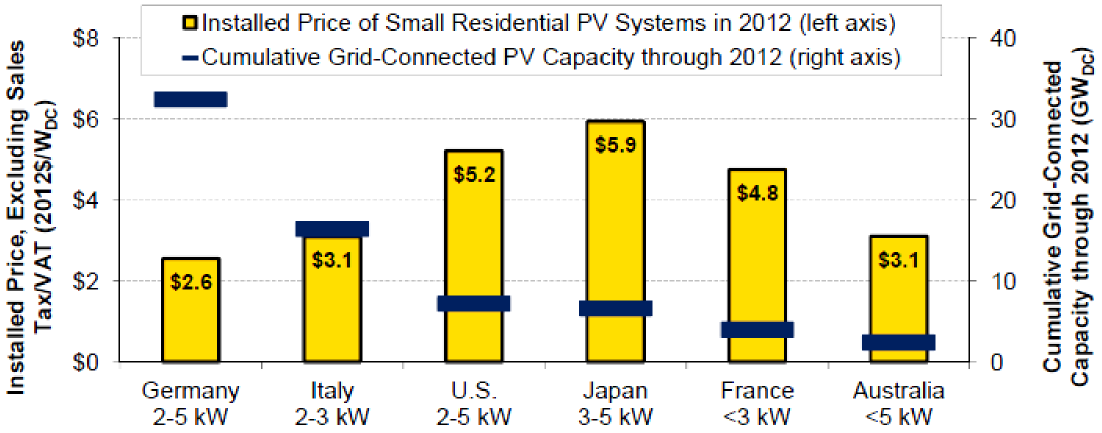


Figure 4. Comparison of the Installed Price for Small Residential PV Systems in 2012 across major national markets (Pre-Sales Tax/VAT) (Barbose et al., 2013)

In California, the latest PV installed costs for 2012 and first half of 2013 shows that the decline in prices for systems installed in 2013 is on pace to match – or perhaps even exceed – the decline observed in 2012. As an indication of this trend, Figure 5 compares the installed price of projects funded through the California Solar Initiative (CSI). As shown, the median installed price of CSI systems installed in first half of 2013 fell by roughly $0.7/W (13%) for systems ≤10 kW, $0.5/W (10%) for systems 10-100 kW, and $0.8/W (15%) for systems >100 kW, relative to the median installed price for systems installed in 2012. If the same price reductions observed transpire more broadly and continue on the same trajectory as in the first half of the year, then US price reductions in 2013 will be even greater than those witnessed in 2012. The first six months of 2013 have seen a gradual stabilization of module prices, which could dampen further reductions in installed system price. That said, the lag between movements in module prices and movements in installed system prices, along with possible further reductions in non-module costs, may allow for a continued reduction in installed prices over the remainder of the year.

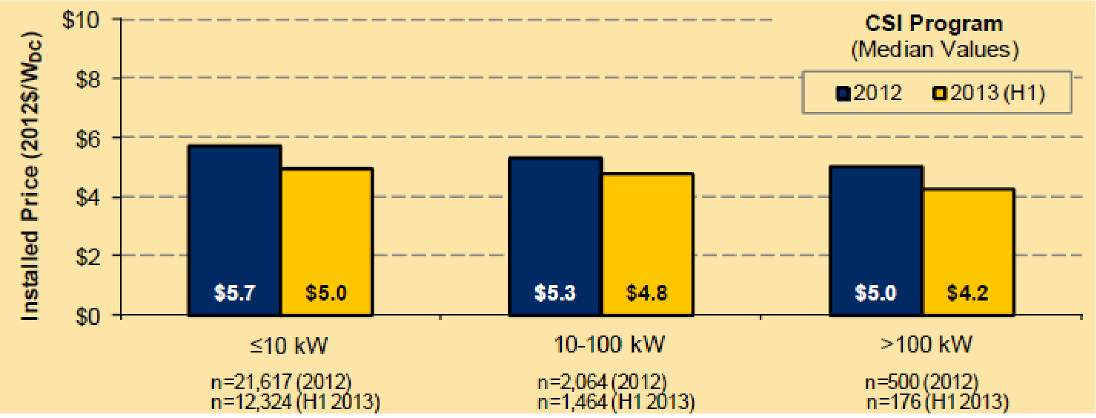
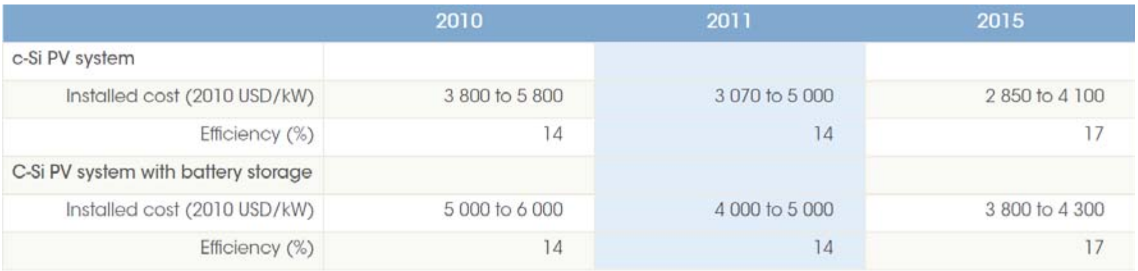


Figure 5. Installed Prices for the CSI Program in 2012 and the First Half of 2013 (Barbose et al., 2013)

In general, based on latest report for global PV cost reduction (IRENA, 2012), it is expected that installed cost of C-Si PV plunge from USD/kW 3800-5800 in 2010 to USD/kW 2850-4100 in 2015. This cost reduction could be even greater for C-Si systems with storage system (Table.3).



	2010	2011	2015
c-Si PV system			
Installed cost (2010 USD/kW)	3 800 to 5 800	3 070 to 5 000	2 850 to 4 100
Efficiency (%)	14	14	17
C-Si PV system with battery storage			
Installed cost (2010 USD/kW)	5 000 to 6 000	4 000 to 5 000	3 800 to 4 300
Efficiency (%)	14	14	17

installed cost and efficiency assumptions for residential PV systems (IRENA, 2012)

Initial costs (Investment) for a BIPV system

There are two ways to analyze the cost of a system: **bottom up cost analysis** and **reported real cost**. In bottom up cost analysis, which is developed by NREL, prices are estimated related to the fix and variable costs which are incorporated in the price of BIPV system. This price estimation disregards the pricing parameters determined by markets, focusing instead on objective inputs and as a means to assess cost-reduction opportunities. In this method, system cost is analyzed by considering all of the materials, labor, regulatory costs, and overhead and profit (O&P) margins for installed residential systems. On the other hand, the **reported real cost** is real reported installed system cost which is more realistic. In the following, we consider all the cost differences between common PV module and BIPV module in: module costs, installation cost, and flexible packaging cost.

- *Modules cost*

For module costs, in comparison with common PV modules, BIPV devices often include additional materials such as framing, flashing, adhesive, etc. to protect the building from different weather condition. Furthermore, BIPV modules are more expensive than common PV modules because of its specific design and more materials it needs. As it is suggested in NREL report, for BIPV module we need to add 10% premium to the cost of commercially available PV module (James et al., 2012).

- *Installation cost*

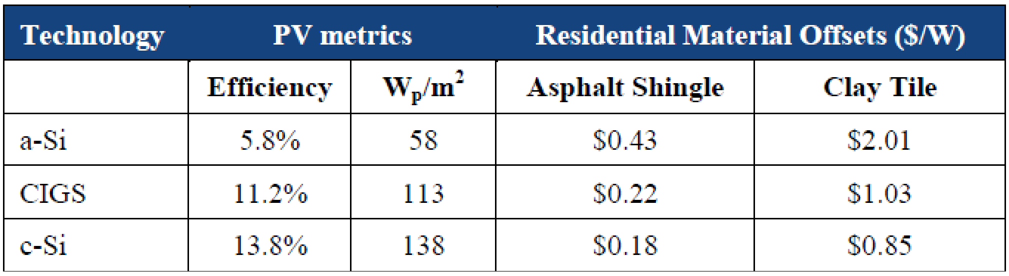
BIPV devices can reduce the installation cost by eliminating racking and mounting hardware, z-channels and associated labor costs. Moreover, since BIPV works as well as building material (roof, window, or shade), the installation cost of BIPV is lower than the traditional construction method (James et al., 2011). Other main part of the installation cost is the overhead and profit (O&P) margins and sales taxes. This cost is defined as a percentage of total system cost. Suggested rates by NREL are 54% overhead, 30% profit and 5% sales tax for O&P.

- *Flexible packaging costs*

Flexible BIPV, with thin film technology (CIGS and a-Si), have some advantages: lower weight (up to 90 % lighter), lower shipping and installation costs, better building area accommodation for building with limited structural support. Flexible BIPV, however, needs top sheet and back sheets that cost about USD 10/m^2. These additional covers add about USD 0.4 USD compared to standard glass-glass packaging (James et al., 2011). Moreover, the efficiency of flexible BIPV is lower than common PV modules.

- *Building material cost off-set (roof)*

A key factor which has not been considered in previous BIPV cost analysis is building material cost off-set. As it is devised, BIPV is a multifunctional product that will replace both traditional building material and PV module. In order to estimate the value of potential off-set for BIPV, we need to compare prices between traditional residential roofing materials and BIPV. Here we should notice that the off-sets are inversely related to PV efficiencies i.e. higher efficient device (c-Si: 113.8%) has less off-set value ($/W) than a less efficient module (a-Si: 5.8%). This is estimated by James et al. (2011) in table 5.



Technology	PV metrics		Residential Material Offsets ($/W)	
	Efficiency	W_p/m^2	Asphalt Shingle	Clay Tile
a-Si	5.8%	58	$0.43	$2.01
CIGS	11.2%	113	$0.22	$1.03
c-Si	13.8%	138	$0.18	$0.85

Table 5. Estimated off-set values for residential BIPV cases (James et al., 2011)

Available data on cost/efficiency comparison for roof-top applications

By considering all the above mentioned factors, it is expected that the common PV price is lower than BIPV. As it is shown in the following figure we can observer that although BIPV modules are more expensive than common PV modules (about 10%), in total, BIPV is cheaper because of off-set shingle, less installation material, less labor cost, less hardware and racking material, lower sales tax and less installer O&P. All these factors are illustrated in figures 9 and10. As it is shown in these figures, at the fourth quarter of the 2011, BIPV price with similar c-Si technology is about $/W 0.98 cheaper than common PV. Cost reductions of the simulated BIPV case are mainly from the elimination of hardware racking and associated labor costs but

BIPV may experience reduced performance compared to rack-mounted PV, impacting levelized costs of energy. In case of the flexible BIPV, because of lower performance about 5.8% (figure 10), its cost is about $/W 5.68 which is considerably higher than normal PV systems and BIPV cost (James et al., 2011, 2012; Sinapis & van den Donker, 2013).

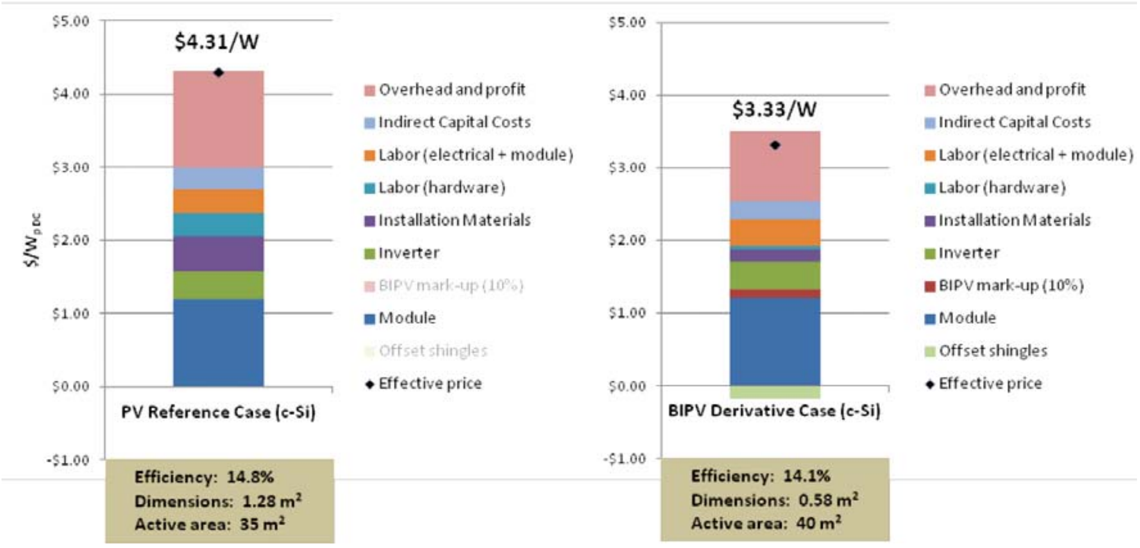


Figure 9. Comparison of installed residential rooftop prices for the PV Reference Case and the BIPV Derivative Case – Q4 2011 estimate (James et al., 2012)

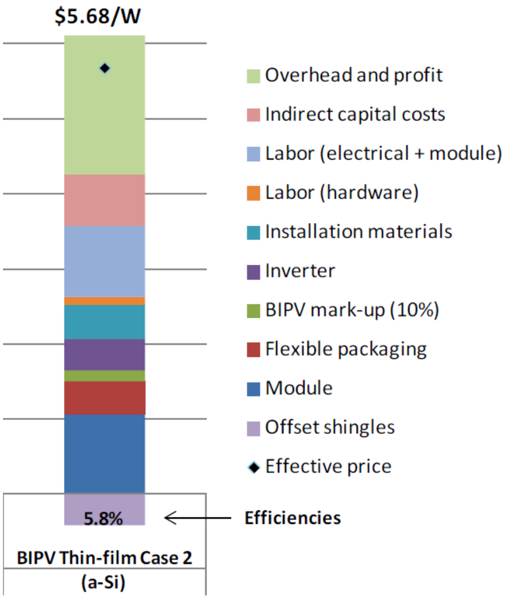


Figure10. installed residential rooftop prices for flexible a-Si BIPV (James et al., 2012)

On the other hand, instead of estimated costs of bottom up cost analysis, we have Reported Real Cost which are more accurate and based on actual installed PV systems. Recent data, though small sample size about the BIPV installation in residential new construction in California (Tracking the Sun VI), shows that the prices of BIPV system in 2012 is 7.6$/W which is notably higher than rack mounted PV systems price $5.3/W. In range of five years, this price difference has increased from $0.7/W in 2008 to $2.3/W in 2012 (Figure.11). However, according to this report, we should consider that these prices does not show both roofing material offset and performance differences between the BIPV and traditional rack-mounted systems (Barbose et al., 2013).

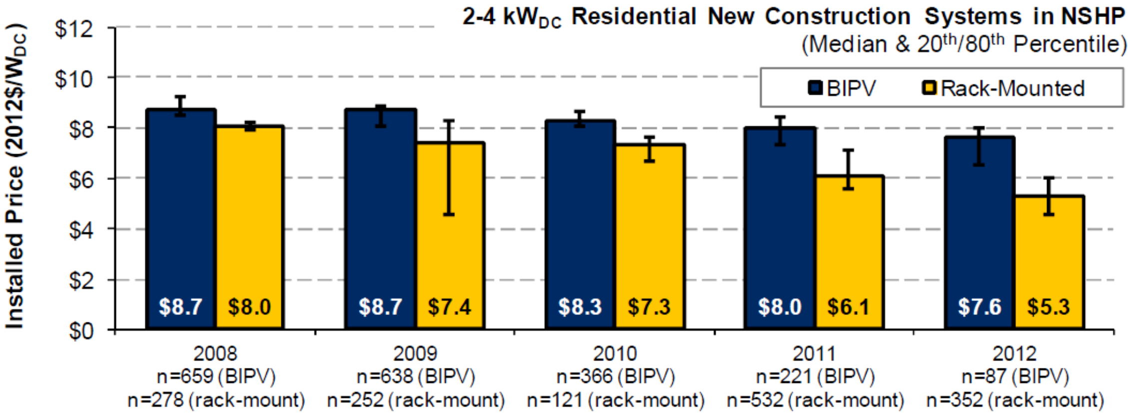


Figure 11. Installed Price of BIPV vs. Rack-Mounted Systems in Residential New Construction (Barbose et al., 2013)

Building-material's costs offset, and performance differences regarding standard PV (for in-roof applications)

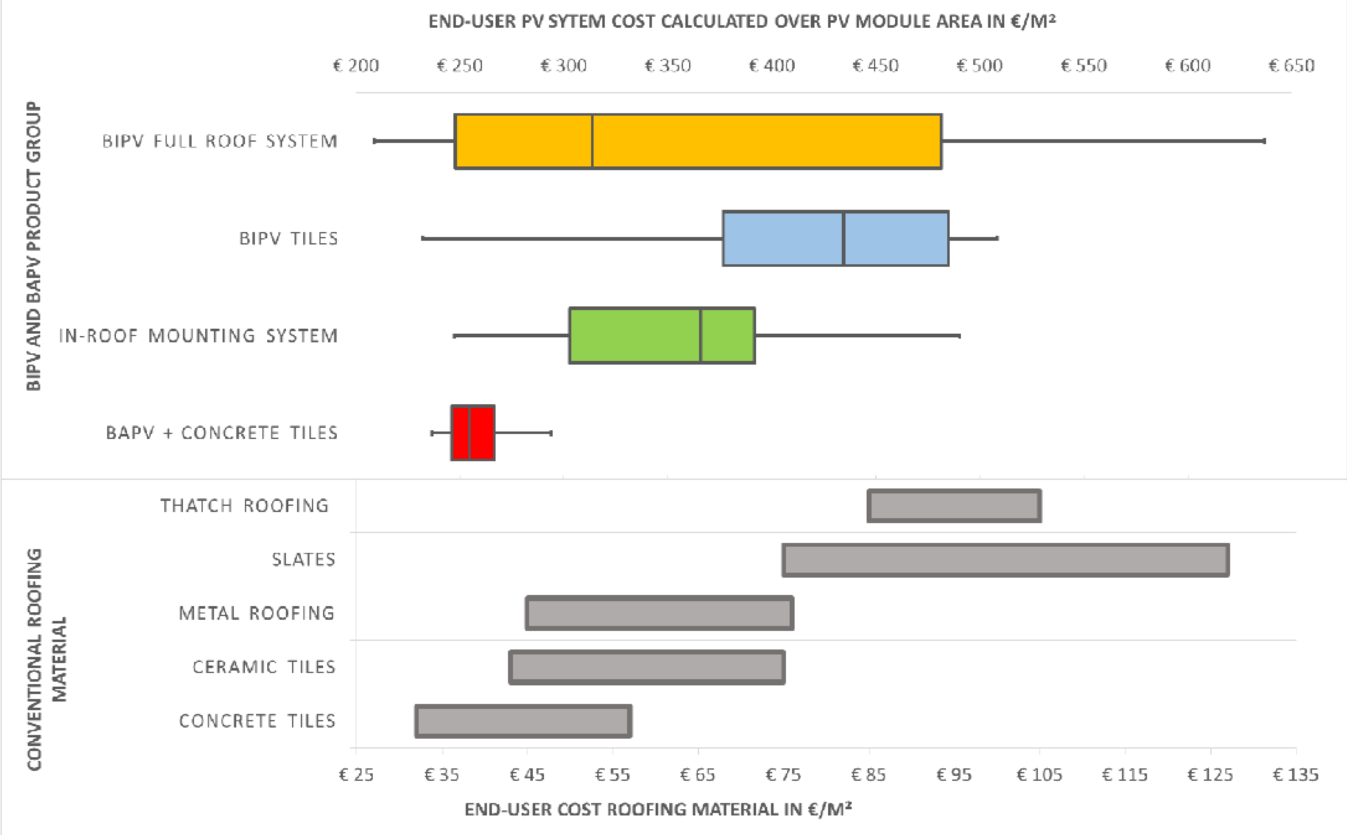
As we have seen, current studies suggest that BIPV is more expensive because it may be sold at a premium price relative to rack- mounted modules (figure.11) due to their additional structural features and functional requirements, and BIPV panel efficiencies are generally lower than typical crystalline module efficiencies in rack-mounted applications, leading to increased area-related balance of systems costs (Barbose et al., 2013). However, a key factor which has not been considered in previous BIPV cost analysis reports is building material cost off-set. As it is devised, BIPV is a multifunctional product that will replace both traditional building material and PV module. In order to estimate the value of potential off-set for BIPV, we need to compare prices between traditional residential roofing materials and BIPV. In the available reports the cost of avoided building material has not considered, and BIPV cost estimation without including this factor is not accurate. But we need to take into account because of different building material and also various types of BIPV this analysis is not an easy task, therefore many people prefer to avoid this complication. A report by James et al., (2011) estimates this off-sets for two different residential materials: clay tile and asphalt shingle (table.5). Here we should notice that the off-sets are inversely related to PV efficiencies i.e. higher efficient device (c-Si: 13.8%) has less off-set value ($/W) than a less efficient module (a-Si: 5.8%).

Investment-costs for BIPV, in terms of cost-per-square-meter.

Some works on the investment costs of a BIPV show the prices/quoting information in terms of €/m ^{2} instead of €/kWp. Results of a survey with this approach, for the European market, divide the cost of BIPV and BAPV (building applied photovoltaic) and also it make distinction between different types of the Roof-BIPV applications: in-roof mounting system, BIPV tiles and full roof BIPV solution. As it is shown in figure.14 the price of concrete and ceramic tiles vary between over 30 €/m² for cheap concrete tiles to almost 75 €/m² for expensive one. This can be explained by the type of roof tile used and also installation cost. Investigating the roof slates we see an even wider price range that varies between almost 75 €/m² to o 125 €/m². The prices of different slate materials play an important role here. For metal roofing the price range can be explained mainly by the thickness of metal and how they are finished. Degreased and painted metal sheets are more expensive. The final conventional roofing material is thatch roofing which costs between 85€ and 105€ per square meter.

The price of products within the BAPV roofing category vary between 225 and almost 300 €/m², this is including the concrete tile underneath. The smaller range indicates the competitive market.

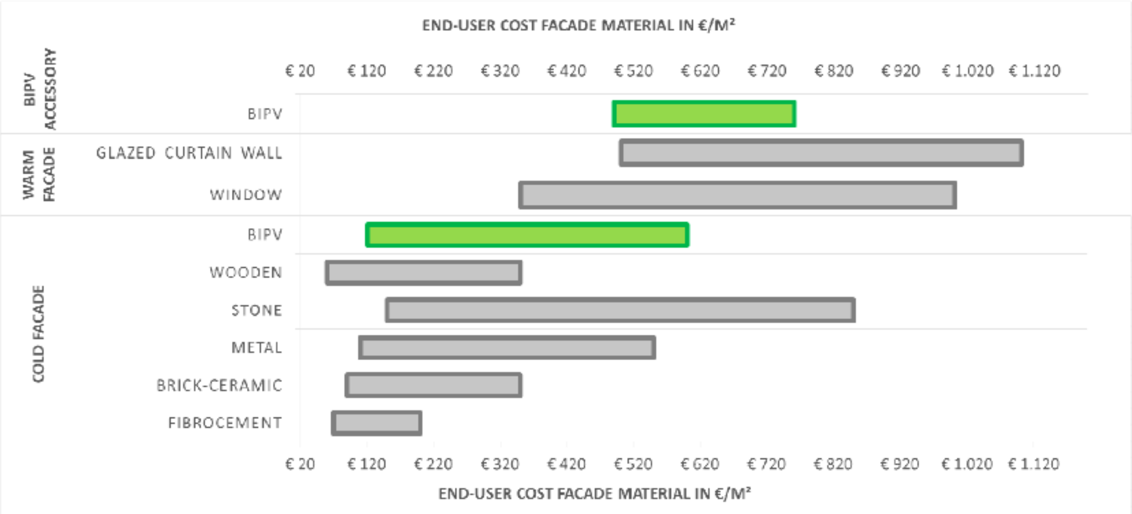
Within the BIPV roofing product groups, we see large price differences. For the in-roof mounting system the price varies between 350€/m² and almost 500 €/m². Although 50% of the prices lie between 300€/m² and 400 €/m². For the BIPV tiles the price varies between 225 and 500 €/m², 50% of the prices lie between 375€/m² and almost 475 €/m². The relative low price of 250 €/m² can be explained by the earlier discussed power density of the BIPV tiles. Furthermore, we see a positive development regarding the emerging BIPV full roof solution. This product group covers the complete price range, from the most cheapest to the most expensive roofing product. The price varies between just over 200 €/m² and almost 650 €/m². Although 25% of the product prices vary between 250 €/m² and just over 300€/m².



Benchmark of conducted price survey comparing conventional roofing material with BAPV and BIPV roofing solutions. (Verberne et al., 2014)

On the other hand, there's the price of the BIPV for façade applications.The BIPV façade applications can be divided into cold façade, warm façade and accessories (such as balconies, parapets, shading devices, etc.). The market of BIPV façade systems in Switzerland and Europe is relatively small and there is still a large cost variety depending on the building type and application. A frequently used argument is the demanded discretion by the customer regarding the project costs. This may be explained considering that very often BIPV facades have been experimented in pilot-demonstrative projects so that the cost was specifically linked to the specific context and influenced by building size, technology adopted, owners policy, etc. Thus the absence of a well established market influenced this phase of benchmarking.

Next figure displays the result of the price survey (€/m²). In BIPV façade product group we can see large price differences. The first group is BIPV accessories such as balcony and sun-shading and for this group price varies between 500 €/m² and 750 €/m². This price for Warm Façade such as glazed curtain wall and windows is higher and the price change varies between 400-500 €/m² and more than 1000 €/m². These results show a wide range price difference for BIPV as façade and this can be explained by relatively small market of this type of technology.



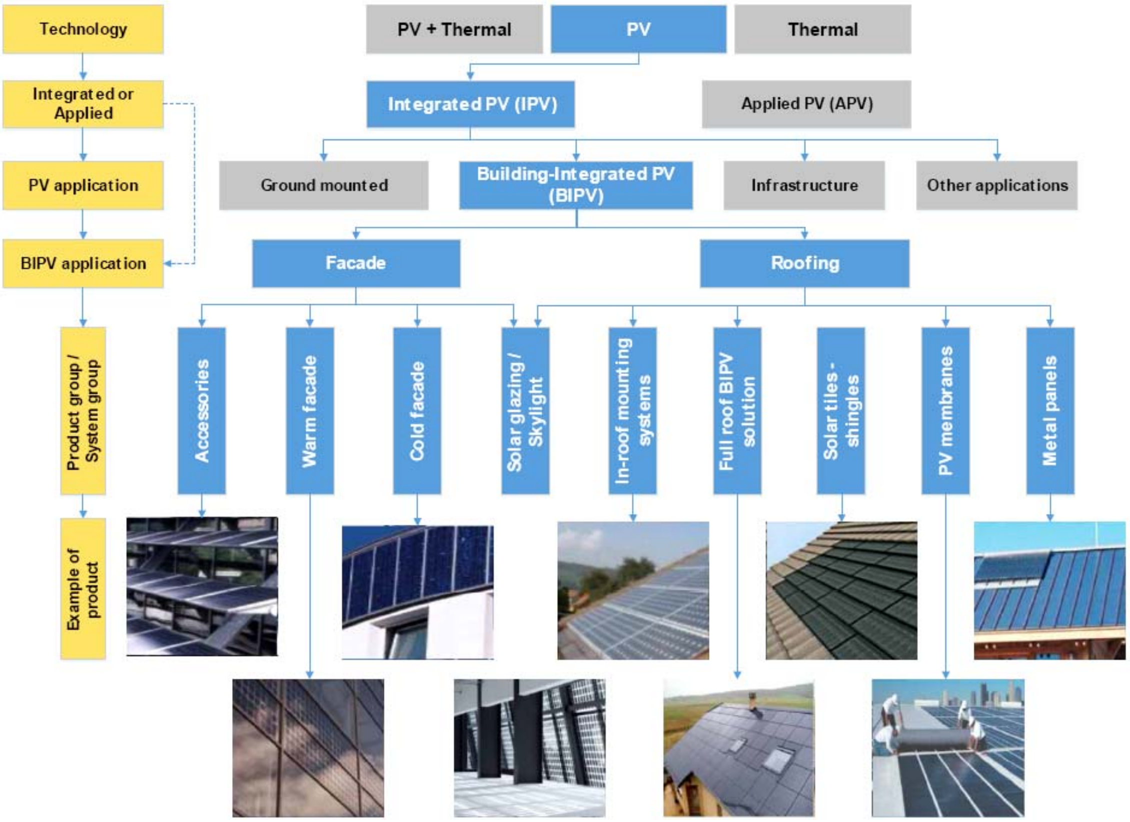
A benchmark of the conducted price survey, comparing conventional roofing materials with BAPV and BIPV roofing solutions. The price is defined as the end-user price and measured in €/m². (Verberne et al., 2014)

3.1.3. Conclusions on an overall approach to BIPV comparative costs

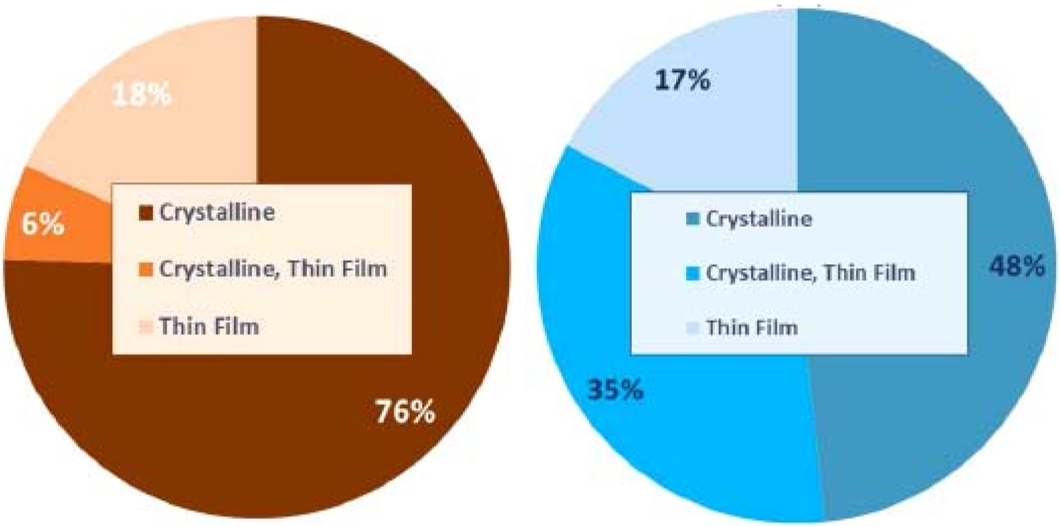
By taking into account the current estate of the arts about BIPV market we can see wide variety of the products available in the BIPV market especially for roofing applications. The most common products are PV tiles and in-roof mounting systems, for façade applications these are warm and cold facades. Mainly crystalline silicon (c-Si) technologies are used for the manufacturing of roof application products. But for the façade applications, thin film (a-Si) technologies have a significant market share. New developments within the BIPV roofing market show a new trend with the emergence of the BIPV full roof systems. Developers, producers and installers looking for complete roof solutions. Using well designed modules with sophisticated mounting systems to increase the ease of installation, enhance the physical building properties and aesthetics of the BIPV system.

The costs and prices of BIPV systems show that the promise of BIPV from an economic perspective has been partially met, but these systems because of the installation costs are still more expensive than conventional PV systems. The lower priced BIPV full roof solutions are price competitive with BAPV roofing solutions. Moreover, the lowest priced full roof solutions are cheaper per square meter. Note that this is probably the case for larger projects, multiple houses so it can benefit from the economies of scale. Furthermore, the low priced products are suitable for roofs that are simple to construct.

BIPV Product categorization



For summarizing current state of the art about the BIPV in European market BIPV -roofing market, the in-roof mounting systems and BIPV tiles, are dominant and represent about 70% of the products within roof market. The BIPV-façade market is smaller in the number of available products and the larger amount of products in the BIPV-roofing market shows that this market is currently considerably bigger than the façade market (Verberne et al., 2014).



Technology used for Roof-BIPV and Façade-BIPV (Verberne et al., 2014)

Moreover, the technology that has been used in façade and roof applications is different. Crystalline Silicon (c-Si) is dominant technology in BIPV-roof market with 75% of the market. This is due to area limitation and this technology higher efficiency. In contrast, thin film technology (a-Si) is mainly used for façade application. It might be because of aesthetic factors, its better performance under undirect radiation and economical reasons. Semitransparent thin film surfaces have the added value of enabling a more uniform distribution of natural light, providing better views from the interior.

However, considering that the thin film technology encompases opac (cladding) and semitransparent modules, the cost range is very wide, depending on the project solution. Opac envelope systems can be more easily adapted to the standardized PV module dimensions, and thus reducing its price. On the other hand, semitransparent thin film applications are usually conditioned by the modulation of the façade, and its construction parameters, which usually reverts on higher prices.

3.2 Costs forecast for the three specific BIPV technologies selected for the Project

In this section we summarise our costs forecast for the three BIPV technologies that the project has chosen to apply in some of the selected public buildings. These three BIPV sub-technologies are:

(1) Glass-laminated crystalline transparent (30% - 40%) modules .

(2) Glass laminated thin film semitransparent (10%-20%) modules.

(3) Thin-film, flexible (EFTE laminated)

and compare the respective costs forecast with the corresponding to standard PV modules (glas + tedlar laminated).

3.2.1 Data for the cost forecast

What follows is a summary of the Costs structure we apply, as well as of the data on the different variables that intervene in such structure. These data are the outcome of the real-time market study or benchmark carried out by the Project team.

▪ Costs structure

As for any decentralised PV project, the basic cost components of a BIPV installation are:

Initial Investment (or ‘Capital Cost’, or ‘CAPEX’):

- **Modules** or photosensitive material
- **Balance of the system**’, BOS)
- Inverters (converters from CC to AC)
- DC/AC Acces (devices and wiring connecting to building electricity network)
- Support sub-system (for placing the modules)
- Transportation from provider to the building .*
- **Installation costs**
    - Installation & mounting works
    - Monitoring sub-system
    - Executive project, commissioning, and legalization & Administrative process

Recurring (each operating year) costs:

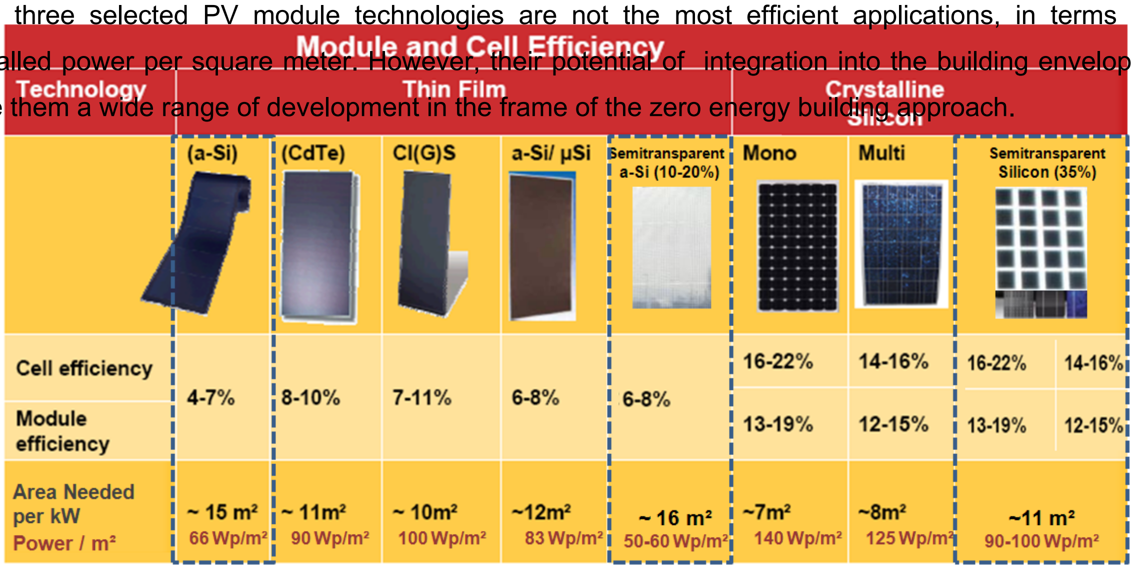
- **Annual operating & maintenance** expenses of the system
- **Financial expenses**, either as interest of a loan taken for financing the above Investment or as an opportunity cost for the owner having immobilized such amount.

(*) Although transportation costs are usually included as part of the equipment order, it was decided to break it down in a specific chapter due to the significant differences for the different Mediterranean regions involved in the Project.

Our forecast for each of these components has consisted in a market exploratory research, trying to determine which could actually be the respective costs for a given BIPV installation to be carried out along 2014-2015.

▪ Modules' cost-forecast

The three selected PV module technologies are not the most efficient applications, in terms of installed power per square meter. However, their potential of integration into the building envelope, give them a wide range of development in the frame of the zero energy building approach.



Module and Cell Efficiency

Technology	Thin Film					Crystalline Silicon			
	(a-Si)	(CdTe)	CI(G)S	a-Si/ µSi	Semitransparent a-Si (10-20%)	Mono	Multi	Semitransparent Silicon (35%)	
Cell efficiency	4-7%	8-10%	7-11%	6-8%	6-8%	16-22%	14-16%	16-22%	14-16%
Module efficiency						13-19%	12-15%	13-19%	12-15%
Area Needed per kW Power / m²	~ 15 m² 66 Wp/m²	~ 11m² 90 Wp/m²	~ 10m² 100 Wp/m²	~12m² 83 Wp/m²	~ 16 m² 50-60 Wp/m²	~7m² 140 Wp/m²	~8m² 125 Wp/m²	~11 m² 90-100 Wp/m²	

Source based on EPIA 2010 , Photon International + own elaboration

BIPV-3 BIPV-2 BIPV-1

In order to complement and confront the generic BIPV research presented at section (3.1) , a preliminary market research has been performed. This research integrates the late up-dated market data from several specialized research institutes (IRENA, NREL, Fraunhofer), PV magazines (PV Magazine, Photon) and calculation softwares (PVSyst database),

The last stage of the cost analysis includes a benchmark study, gathering real quotations from European potential providers. These "pre-offers", including technical features and prices, allowed us to identify the suitable providers for PV modules and BOS components.

Comprehensive information was gathered from the following companies:

PV modules:

Onyx Solar Energy (Spain), Vidurglass (Spain), Sunerg (Unisolar) (Italy), Sunset (Germany) – Sunset – BIC (Egyptian official distributor).

The benchmarking is linked to real projects, with an average size of 10 kWp and located in several Mediterranean regions, allowed us to collect precise information, showing the sensitivity of the different technical parameters.

By putting together the results of both market research stages and analysing the so accumulated information, we have elaborated a 'real-case', 2014, forecast for modules' prices, technical features and yield, for each of the three BIPV technologies.

It must be underlined that, while the standard PV industry use to quote their modules (items) in terms €/ per-Wp, the BIPV sector also expresses PV modules costs in terms of €/ unit and €/m2.

To sum up, our overall forecast data on market availability modules and likely average prices for 10 kWp systems is the following

Technology	Dimensions	Other technical features: Thickness and trasnparency	**Average price forecast ***	Remarks
BIPV-1 Semitransparent Crystalline	Average	Lamminated PVB/EVA 5+1,5+5 mm Transparency: 20-40%	2,5 €/Wp	* An average cost has been settled, based on project real quotations
	Average (standardized) 1800 x 1200 mm approx.	Transparency: 20 – 30 %	1,30 – 2,93 €/Wp	It depends a lot on the glass composition and provider
	Special dimensions (eg: 2500 x 600 – 1200 mm)	Transparency: 20 – 40 %	2,71 – 3,26 €/Wp	
	Special thickness (Eg: 29 mm, air chamber)	Transparency: 20 – 40 %	2,92 – 3,67 €/Wp	It depends a lot on the glass thickness and properties (solar factor, thermal transmittance)
BIPV-2 Semitransparent Thin film	1.100 x 1.300 mm. 1.300 x 1.245 1.200 x 600	Transparency: 10-20%	2 - €/Wp	* An average cost has been settled, based on project real quotations
	Average (standardized) (eg: 1100 x 1300 mm; 1245 x 1242 mm; 1200 x 600 mm)	Opac and semitransparency 10-20%	1,00 – 4,65 €/Wp	
	Special dimensions	Semitransparency 10-20-30%	4,50 – 6,14 €/Wp	
BIPV-3 Flexible thin film	Larger standardized dimensions: 5.486 x 394 mm.	Opac	1,5 €/Wp	comparative few market offerers.

(*) Less: Saving from not expending in an alternative ordinary building-material

Different from standard PV modules, any type of BIPV modules comes as substitute for an ordinary outside-cover building-material –be glass, tiles, etc. Therefore, the Investment in a BIPV installation implies also a saving in some type of ordinary building-material. Thus, for example, a BIPV-1 system with a surface of 100 m^2 is saving the costs of the same surface of ordinary laminated glass with the same physical features (thickness, air chamber, .etc.) that otherwise the building would require. And parallel examples could be put regarding BIPV-2 and BIPV-3.

Therefore, in order to estimate the comparative cost-per-kWh of a BIPV installation we will have to deduct from the modules' costs the corresponding saved costs in a given alternative ordinary building-material offset. And, since such alternative building-material would also require some 'installation' costs, a parallel provision on saving should be made regarding Installation Costs.

▪ Complementary equipment (Balance-of-the-system, BOS)

For our cost forecast we have followed the same two-stages market study approach as for modules. In that case however, the our conclusion has been that there are few relevant differences in costs forecast regarding the three different BIPV technologies.

As for modules, also for BOS components the usual in industry is not to quote unit-prices for a given equipment, but to quote their prices in terms of cost-per-unit-of-power of the concerned system (€/Wp).

The outcome from our analysis on respective costs forecast for BIPV installations to be carried out along 2014-2015 can be summarized as follows:

Inverters, management system and monitoring: manufacturers (distributors)

SMA, Circutor (Circutor, Kostal, Fronius, Delta), Assolar (Delta), Technosun (Kostal).

The benchmarking is linked to real projects, with an average size of 10 kWp and located in several Mediterranean regions, allowed us to collect precise information, showing the sensitivity of the different technical parameters.

Cost forecast for complementary equipment (BOS)

Cost component	**average price forecast**	remarks
Inverters	0,35 €/Wp	Have to be replaced each 10 years. For a Standard PV system: 0,25 €/Wp
DC/AC accessories, combiner boxes, cabling and electrical components	0,10 €/Wp	
Support system components	0,45 €/Wp 0,20 €/Wp 0,35 €/Wp	for BIPV-1 and BIPV-2 for BIPV-3 for Standard PV
Transport (from provider to host building site)	0,25 €/Wp	Estimate for Barcelona area placements

▪ Installation services

We have followed the same twofold market-study approach for determining reliable forecast for for actual-market costs of the involved installation services, for BIPV systems to be implemented along 2014-2015. Again –as for modules and BOS elements- the usual in the industry is here to quote cost in terms of €/Wp. And, as for BOS elements, we have also conclude that there are not too much differences in Installation cost for systems of one or other BIPV option.

This is our summary for our cost forecast determinations as for systems to be installed along 2014-2015:

Cost forecast for Installation Services

Cost component	**average price forecast**	remarks
Installation properly said, and mounting	0,60 €/Wp	The equivalent for Standard PV is 0,31 €/WEp
Monitoring subsystem (local and remote)	0,25 €/Wp	
Engineering and legalization (Executive project for the Installation, commissioning, legalization & Administrative processes)	0,25 €/Wp	

▪ Operating & Maintenance Costs

The result from our local (Barcelona area) market study has been a forecast of 432 €/year for a 10kWp system, whatever the specific type of PV technology. With no relevant differences regarding the type of PV technology. According to our market analysis, we estimate this amount is valid as forecast for all the PV system productive years –in real terms, apart from inflation: We have not detected any consistent reason for a time-trend either upward or downward.

▪ Operating useful life of the system

We have found a broad acceptance by both specialised institutions' reports and industry's professionals of the assumption on taking 25 years as the useful life of any PV system. With the exception of the inverters, which estimate useful life is 10 years, as has been already pointed out.

▪ Annual Electricity expected to be generated by the system

Whichever be the PV technology chosen, for a system with a given power-capacity (Wp), the number of kWh it is expected to produce per year –or, in more technical terms, the *'Annual Energy Performance Ratio per kWp'*, ***P*** - depends on:

- Geographical placement, which is associated to a given level of sun hours radiation and incidence angle.

- Orientation of the system (South, South-east, … etc), which can come limited by the host building's specific available surface for receiving the system
- Tilt of the panels –or solar field- regarding the horizontal, which, again can come limited by the features of the host building's receiving surface

The interplaying of these three variables has been worked out by the Project Technical Team, in order to determine *Annual Energy Performance* ratios for all of these variables combinations that are relevant for the Project's scheduled applications. That is, taking into account the sun radiation parameters for the Mediterranean Regions the Project works on, the different features of the specific buildings that have been selected for hosting the Project's Installations, as well as the type of BIPV planned for those buildings. The resulting quantitative determinations for the respective *Annual Energy Performance ratios* have been stated in the internal working document '4.3.2.5-05 Technologies table BIPV' (which can be available under request).

3.2.2 Cost forecast (per kWh) for the three types of BIPV to implement in the Project

We apply here the above cost and technical data forecasted to determine the overall costs estimates for each of the three BIPV technologies the Project is going to implement: Costs for each system component –Investment costs and recurring annual costs- and resulting **cost per kWh** –which is the key concept for comparing electricity cost.

For doing that –at the time that for simplifying the presentation of the data- our calculation procedure is based in assuming –by way of example- that the a BIPV system to implement has a power capacity of 10 kW. Then, we calculate costs in the case it was of BIPV-1 technology, then if of BIPV-2, and then if of BIPV-3. And we complement that by showing a parallel calculation if the system was based in standard PV technology –for taking it as an external well known reference in terms of costs.

And, as far as system's output (kWh/year) for each technology we take the corresponding ***P*** ratio for a specific case of placement-orientation-tilt for the system:

- Geographical placement (insolation parameters): *Barcelona area*
- Orientation of the system's solar field: *South*
- Tilt of the solar field: *30º degrees regarding ground*.

Finally, for calculating the unit cost, Cost per-KWh, we follow the usual methodology of ***average annual costs and output*** we have summarised before (section 1.1.2) that is, to make the calculation on the grounds of annual average costs and yield.

Thus, we start by annualizing Investment cost (usually referred to in the literature as "CAPEX", for '**cap**ital **ex**penditure'),

$$\sum \frac{INVESTMENT\ \ COSTS}{Useful\ \ life\ (YEARS)}$$ = Investment Annual share, (or *Amortisation quota*) = IA

that is, making a linear distribution of the initial Investment along the expected number of productive years of the system (25 years, except for inverters, for which we take 10 years). In accordance with that, then we take into account the annual financial costs derived from such investment.

An alternative path for annualizing initial investment is the following: To assume that the person or Entity which is the owner of the building –and therefore is going to pay fopr the system- will have to ask for a loan for financing the initial Investment. This loan to be paid back by constant annuities along so many years as the system operating life. Which would be such constant annuity? There is a well know formula that gives us the answer, according to a given rate of interest [21].

The amount of this Constant Annuity, CA, is something higher than the above Investment's *Amortisation Quota*, IA (so long that the interest rate chosen for applying the former be not 0). The difference is in fact the extra money the investor should pay as loan's interests. Therefore, that difference, *CA-IA=FC* can be considered as the annualised *financial cost* for the Investment required by the solar system.

Our option here has been to consider *CA* as the annualized Investment costs. But breaking it down in its two above components: *IA* and *FC*; that is, as the sum of "*Amortisation quota*" plus *"Financial cost*".

For the above annualisation, we take as interest rate ***r***=2%. This seams a reasonable assumption, since in most cases there exist public programmes offering loans for solar-power installations with interest-rate below market rates, and in turn market interest rates in most countries are being last years as low as 3-5% (with expectations of they keeping so low for long). So, the appropriate value to choose for ***r*** in calculating CA and therefore FC should likely be around 2%, if not lower.

In calculating CA we take into account that the useful life for inverters is different (shorter) than for the rest of the initial investment. That is, we calculate separatedly the CA (and therefore, IA and FC) for the initial investment excluding inverters, and the CA for the investment in inverters. And then we sum up both (see more detailed explanation after table for BIPV-1)

The next step of our calculation is just to sum the above "annualized Investment costs" with the operating & maintenance costs per year, *M*, and then dived by the *kWh-per-year* expected from the system -which comes out from multiplying the system size or capacity, kWp, by the *annual*

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[21] Standard *Constant annuity* calculation formula:

Constant Annuity payment = (***Loan***) . $\frac{r \cdot (1+r)^n}{(1+r)^n - 1}$; or, in a more compact notation: CA = $L \cdot \frac{r}{1-(1+r)^{-n}}$;

where ***r*** = the rate of interest, and ***n*** the number of years.

It may be verified that for a insignificant interest rate, close to 0, the CA becomes simply = L/n *performance ratio, P*, for the corresponding technology and a given placement, orientation and tilt of the solar field:

$$\textbf{Cost-per-kWh} = \frac{(IA + FC) + M}{kWh\_year} \quad ; kWh\_year = kWp \cdot P$$

This calculation process is here applied, as pointed out above, to each of the three BIPV technologies, plus the standard PV modules one, for comparative purposes. And in the four cases it is applied taking as annual performance ratio the one corresponding to a specific set of conditions regarding geographic placement (Barcelona area), orientation (South), and tilt (30º regarding ground). However, we complete that by carrying out a sensibility analysis of the resulting unit costs for different physical conditions: How the cost-per-kWh varies when we change tilt, orientation, and geographical placement (across Mediterranean Regions), respectively.

The corresponding quantitative results for the complete cost-calculation sequence are shown in the following 5 tables:

Electricity cost for a 10 kWp BIPV system's size (power capacity), in a given Mediterranean placement and positioning [(a)]

BIPV-1: Glass-laminated, crystalline semi-transparent (30-40%)

(a) Placement, Barcelona area; positioning, orientation South, tilt 30º

		€/Wp		
	Reference-power system (kWp)		10 kWp	
(1)	Required modules' surface 10.000Wp/95 Wp/m^2		105 m^2	
(2)	Modules cost, (price given in terms of €/Wp)	2,50	25.000 €	
	Balance of System (BOS):			
(3)	Inverters	0,35	3.500 €	
(4)	DC/AC Access	0,10	1.000 €	
(5)	Support System	0,45	4.500 €	
(6)	Transportation (Barcelona area)	0,25	2.500 €	
(7)	Subtotal equipment cost for the system	3,65	36.500 €	
	Installation cost:			
(8)	Installation/ mounting	0,60	6.000 €	
(9)	Monitoring system	0,25	2.500 €	
(10)	Executive project, commissioning, and legalization & Administrative process (Barcelona area)	0,25	2.500 €	
(11)	Subtotal system Installations costs	1,10	11.000 €	
(12)	**Total Initial Investment cost ,**	= (7) + (11)		47.500 €
	Initial Investment Cost, per Wp; = (12)/1000x(1)	4,16		
(13)	Saving from offset building-material: (1)x 68,4 €/m^2 (*)	-0,72	- 7.180 €	
	Cost of the electricity generated			
(14)	System operating life (except for inverters)			25 years
(15)	Initial Investment annual amortization quota; linear	= [(12)–(3)] /(14) + (3)/10		2.110,00 €
(16)	Financial cost (cost for interest, or, opportunity costs)	see (**)		536,00 €
(17)	Annual maintenance costs			432,00 €
(18)	Total system annualised costs,	= (15)+(16)+(17)		3.078,00 €
(19)	Annual electricity generation per kWp (P)	performance ratio: Barcelona area, South, 30º tilt		1262 kWh
(20)	Total system annual generation/savings	= (19) x (1)		12.620 kWh
(21)	**Cost per kWh,**	= (18)/(20)		**0,244 €**
(22)	**Cost per kWh**, taking into account saving (13) (***)	= (21) - [CA of (13)/ (20)]		**0,215 €**

(*) *Cost of the ordinary building-material the BIPV modules substitute to.* -Non-PV glass of similar features (dimension, thickness, air chamber, ..) has a 2014's market price of around 57 €/m^2 . And the Installation costs for it may be estimated as 20% of such material cost . Then: 57 x (1+0,2) = 68,4 €.

(**) *Financial costs* (payments for interest, or opportunity costs).- It has been calculated as the difference between the *Constant annuity* for the Investment Costs (*CA*) and the linear 'annual amortisation quota' (IA) for those Investment Costs. That calculation has been made taking into account that the useful life of the equipment is 25 years, except for the Inverters, that is 10 years; and assuming an interest rate of 2%.

Thus: *CA* for (47.500-3.500) € at 25 years ➔ 2.254 €; *CA* for 3.500 € at 10 years = 392 €.; then, *total CA*=2.254+392=2.646 €. And as far as the simple *amortization quota*: *IA*=(47.500-3.500)/25 + 3.500/10 = 2.110 €. Therefore the difference *CA-IA=FC* = 2.646-2.110 = 536 €, as *'Financial Costs'*.

In the case the building proprietor would have to finance the initial Investment asking for a loan, that amount of 536 € would correspond to annual payments as interest, non-capital payback. And in the case the building proprietor had not need of asking for a loan for financing its investment in the BIPV system, the referred amount would then be *opportunity costs*: the annual amount of otherwise financial earnings it is renouncing to by investing its 47.500 € cash in the solar system instead of in, f.e., State's bonds.

(***) *Repercussion of the saving*, in terms of cost-per-kWh: *CA* for the saving (7.180 €), divided by kWh-year (12.620) = -0,029 €. Therefore, 0,244 – 0,029 = 0,215 €/kWh.

- ♣ -

To make it more formally explicit, the above –as well as the tables that follow- implies to apply the following calculation formula for the Cost-per-kWh, which means, in short, to divide ***total annualized costs*** by ***annual*** (average) ***output in kWh*** :

$$\text{€/kWh} = \frac{\left\lfloor I/n + cI/m + FC + M \right\rfloor_{for\ a\ given\ kWp}}{P \cdot kWp}$$

where:

I = Initial Investment expenses; i.e., the sum of Equipment costs (modules and BOS, excluding inverters) plus Installation costs.

n = Number of productive years of the system; or estimated useful life. We have assumed n=25 years.

cI = Complementary investment: Inverters, which must be replaced each m years. We have assumed m=10 years.

FC = Financial annual costs. They have been calculated as $CA[I] + CA[cI] - (I/n + cI/m)$

M = Annual operating and maintenance costs

P = Electricity performance ratio, for the specific technology. I.e., kWh generated per year, per 1 kWp.

$kWp = 10$

Which implies the following assumptions:

1) P is an average for the n years. Or, alternatively: modules' yield degradation rate along the productive years is not relevant.
2) M, annual maintenance costs will remain approximately constant along the productive period –in real terms (i.e., apart from inflation).

Electricity cost for a 10 kWp BIPV system's size (power capacity), in a given Mediterranean placement and positioning [(a)]

BIPV-2: Glass-laminated, crystalline thin-film (semitransparent: 10-20%)

(a) Placement, Barcelona area; positioning, orientation South, tilt 30º

		€/Wp		
(1)	Reference-power system (kWp)		10 kWp	
	Required modules' surface 10.000Wp/55 Wp/m^2		182 m^2	
(2)	Modules cost, (price given in terms of €/Wp)	2,00	20.000 €	
	Balance of System (BOS):			
(3)	Inverters	0,35	3.500 €	
(4)	DC/AC Access	0,10	1.000 €	
(5)	Support System	0,45	4.500 €	
(6)	Transportation (Barcelona area)	0,25	2.500 €	
(7)	Subtotal equipment cost for the system	3,65	31.500 €	
	Installation cost:			
(8)	Installation/ mounting	0,60	6.000 €	
(9)	Monitoring system	0,25	2.500 €	
(10)	Executive project, commissioning, and legalization & Administrative process (Barcelona area)	0,25	2.500 €	
(11)	Subtotal system Installations costs		11.000 €	
(12)	**Total Initial Investment cost ,**	= (7)+(11)		42.500 €
(13)	Initial Investment Cost, per Wp; = (12)/1000x(1)	4,25		
(13)	Saving from offset building-material: (1)x (..) €/m^2 (*)		t.b.d. €	
	Cost of the electricity generated			
(14)	System operating life (except for inverters)			25 years
(15)	Initial Investment annual amortization quota; linear	= [(12)–(3)] /(14) + (3)/10		1.910,00 €
(16)	Financial cost (cost for interest, or, opportunity costs)	(**)		480,00 €
(17)	Annual maintenance cost			432,00 €
(18)	Total system annualised costs,	= (15)+(16)+(17)		2.822,00 €
(19)	Annual electricity generation per kWp (P)	performance ratio Barcelona area, South, 30º		1.345 kWh
(20)	Total system annual generation/savings	= (19) x (1)		13.450 kWh
(21)	**Cost per kWh,**	= (18)/(20)		**0,201 €**
(22)	**Cost per kWh**, taking into account saving (13) (***)	= (21) - [CA of (13)/ (20)]		

(*) *Cost of the ordinary building-material the BIPV modules substitute to*

(**) *Financial Costs*; (see previous explanation for BIPV-1).- *CA* for (42.500-3.500) € at 25 years + *CA* for 3.500 € at 10 years = 2.390 €. Then, *Financial Costs* = 2.390 € – 1.910 € = 480 €.

(***) *Repercussion of the saving* in terms of €/kWh

Electricity cost for a 10 kWp BIPV system's size (power capacity), in a given Mediterranean placement and positioning [(a)]

BIPV-3: Thin-film, flexible (EFTE laminated)

(a) Placement, Barcelona area; positioning, orientation South, tilt 30º

		€/Wp		
(1)	Reference-power system (kWp)		10 kWp	
	Required modules' surface 10.000Wp/66 Wp/m^2		152 m^2	
(2)	Modules cost, (price given in terms of €/Wp)	1,5	15.000 €	
	Balance of System (BOS):			
(3)	Inverters	0,35	3.500 €	
(4)	DC/AC Access	0,10	1.000 €	
(5)	Support System	0,20	2.000 €	
(6)	Transportation (Barcelona area)	0,25	2.500 €	
(7)	Subtotal equipment cost for the system	2,40	24.000 €	
	Installation cost:			
(8)	Installation/ mounting	0,60	6.000 €	
(9)	Monitoring system	0,25	2.500 €	
(10)	Executive project, commissioning, and legalization & Administrative process (Barcelona area)	0,25	2.500 €	
(11)	Subtotal system Installations costs		11.000 €	
(12)	**Total Initial Investment cost ,**	= (7)+(11)		35.000 €
(13)	Investment Cost, per Wp; = (12)/1000x(1)	3,50		
(13)	Saving from offset building-material: (1)x (..) €/m^2 (*)		-t.b.d. €	
	Cost of the electricity generated			
(14)	System operating life (except for inverters)			25 years
(15)	Initial Investment annual amortization quota; linear	= [(12)–(3)] /(14) + (3)/10		1.610,00 €
(16)	Financial cost (cost for interest, or, opportunity costs)	(**)		395,00 €
(17)	Annual maintenance cost			432,00 €
(18)	Total system annualised costs,	= (15)+(16)+(17)		2.437,00 €
(19)	Annual electricity generation per kWp (P)	performance ratio Barcelona area, South, 30º		1.354 kWh
(20)	Total system annual generation	= (19) x (1)		13.540 kWh
(21)	**Cost per kWh,**	= (18)/(20)		**0,18 €**
(22)	**Cost per kWh**, taking into account saving (13) (***)	= (21) - [CA of (13)/ (20)]		

(*) *Unit cost of the ordinary building-material the BIPV modules substitute to.*

(**) *Financial Costs*; (see previous explanation for BIPV-1).- *CA* for (35.000-3.500) € at 25 years + *CA* for 3.500 € at 10 years = 2.005 €. Then, *Financial Costs* = 2.005 € – 1.610 € = 395 €.

(***) *Repercussion of the saving* interms of €/kWh.

Electricity cost for a 10 kWp BIPV system's size (power capacity), in a given Mediterranean placement and positioning (a)

Standard PV crystalline modules (glass + tedlar laminated)

(a) Placement, Barcelona area; positioning, orientation South, tilt 30º

		€/Wp		
(1)	Reference-power system (kWp)		10 kWp	
	Required modules' surface 10.000Wp/140 Wp/m^2		72 m^2	
(2)	Modules cost, (price given in terms of €/Wp)	0.49	4.900 €	
	Balance of System (BOS):			
(3)	Inverters	0,25	2.500 €	
(4)	DC/AC Access + protection and system grounding	0,10	1.000 €	
(5)	Support System	0,35	3.500 €	
(6)	Transportation (Barcelona area)	0,25	2.500 €	
(7)	Subtotal equipment cost for the system	1,44	14.400 €	
	Installation cost:			
(8)	Installation/ mounting	0,31	3.100 €	
(9)	Monitoring system	0,25	2.500 €	
(10)	Executive project, commissioning, and legalization & Administrative process (Barcelona area)	0,25	2.500 €	
(11)	Subtotal system Installations costs	0,81	8.100 €	
(12)	**Total Initial Investment cost ,**	= (7)+(11)		22.500 €
(13)	Investment Cost, per Wp; = (12)/1000x(1)	2,25		
	Cost of the electricity generated			
(14)	System operating life (except for inverters)			25 years
(15)	Initial Investment annual amortization quota; linear	= [(12)–(3)] /(14) + (3)/10		1.050,00 €
(16)	Financial cost (cost for interest, or, opportunity costs)	(**)		262,00 €
(17)	Annual maintenance cost			432,00 €
(18)	Total system annualised costs,	= (15)+(16)+(17)		1.746,00 €
(19)	Annual electricity generation per kWp (P)	Energy performance ratio: Barcelona, South, 30º		1.262 kWh
(20)	Total system annual generation/savings	= (19) x (1)		12.620 kWh
(21)	**Cost per kWh,**	= (18)/(20)		**0,138 €**

(**) *Financial Costs*; (see previous explanation for BIPV-1).- *CA* for (22.500-2.500) € at 25 years + *CA* for 2.500 € at 10 years = 1.312 €. Then, *Financial Costs* = 1.312 € – 1.050 € = 262 €.

Summary of costs forecast for the three BIPV options analyzed here –for a 10 kWp system's size- in a given Mediterranean placement and positioning [(a)], comparing also with standard PV

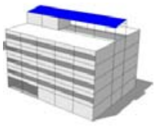
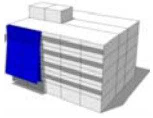
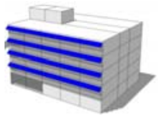
(a) Barcelona area, South oriented, 30º tilt, in roof

		BIVP-1 Crystalline semi-transparent, 30-40 %	BIPV-2 Thin-film a-Si 10-20 % transp-	BIPV-3 Thin-film flexible	Standard PV
	Size/capacity of the system	10 kWp	10 kWp	10 kWp	10 kWp
	Required solar field total surface (m^2)	105	182	152	72
	Equipment costs	36.500 €	31.500 €	24.000 €	14.400 €
	Installations costs	11.000 €	11.000 €	11.000 €	8.100 €
(1)	Total initial (investment) costs	47.500 €	42.500 €	35.000 €	22.500 €
	Per-unit-of-power Investment costs	4,75 €/Wp	4,25 €/Wp	3,5 €/Wp	2,25 €/Wp
(2)	Saving from offset building-material	7.180 €	tbd €	tbd €	--
	System operating life (except for Inverters)	25 years	25 years	25 years	25 years
	Annual Energy performance per kWp, for (a)	1.262 kWh	1.345 kWh	1.354 kWh	1.262 kWh
(3)	Annual electricity generation, for (a)	12.620 kWh	13.450 kWh	13.540 kWh	12.620 kWh
	Annual operating and maintenance costs	432 €	432 €	432 €	432 €
	Initial Investment annual amortization	2.110 €	1.910 €	1.610 €	1.050 €
	Financing costs of the initial Investment	536 €	480 €	395 €	262 €
(4)	Total annual-equivalent costs	3.078 €	2.822 €	2.437 €	1.746 €
	Cost per kWh **[= (4)/(3)]**	**0,244 €**	**0,201 €**	**0,18 €**	**0,138 €**
	Cost per kWh taking into account saving (2)	**0,215 €**	t.b.d. **€**	t.b.d. **€**	**-**
Source: Previous tables					
Sensibility analysis (I): Unit-cost sensibility to **locations,** (keeping the optimal positioning: South/ 30º)					
Alexandria and Marsa-Matruh (Egypt) (b)					
	Annual Energy performance per kWp,	1.767 kWh/kWp	1.895 kWh/kWp	1.704 kWh/kWp	1.767 kWh/kWp
	Cost per kWh [=(4)/10x(5)]	0,174 €	0,149 €	0,143 €	0,100
Chania (Greece)					
	Annual Energy performance per kWp,	1.602 kWh/kWp	1.836 kWh/kWp	1.667 kWh/kWp	1.602 kWh/kWp
	Cost per kWh	0,192 €	0,154 €	0,146 €	0,109 €
Al-Salt (Jordan)					
	Annual Energy performance per kWp,	1.569 kWh/kWp	1.789 kWh/kWp	1.653 kWh/kWp	1.569 kWh/kWp
	Cost per kWh	0,196 €	0,158 €	0,147 €	0,111 €
Source: Previous tables, and for Annual energy performance ratios': Our internal Working Document "Technologies table_BIPV_EsE.xlsx" 4.3.2.5 / 05. *Based on PVSyst v5.55 simulations*					

(b): It is the best placement & positioning as far as Annual Energy Performance ratios, if tilt not beyond 30º

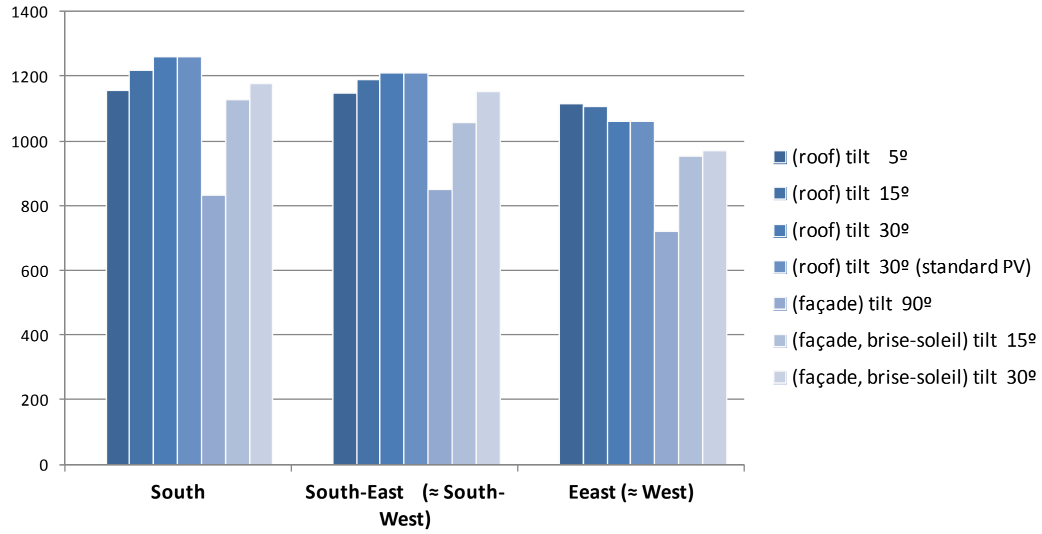
Sensibility analysis (II): Unit-cost sensibility to **placement, orientation & tilt angle**, (Energy production (kWh/kWp) ratio)

for a given PV technology and location

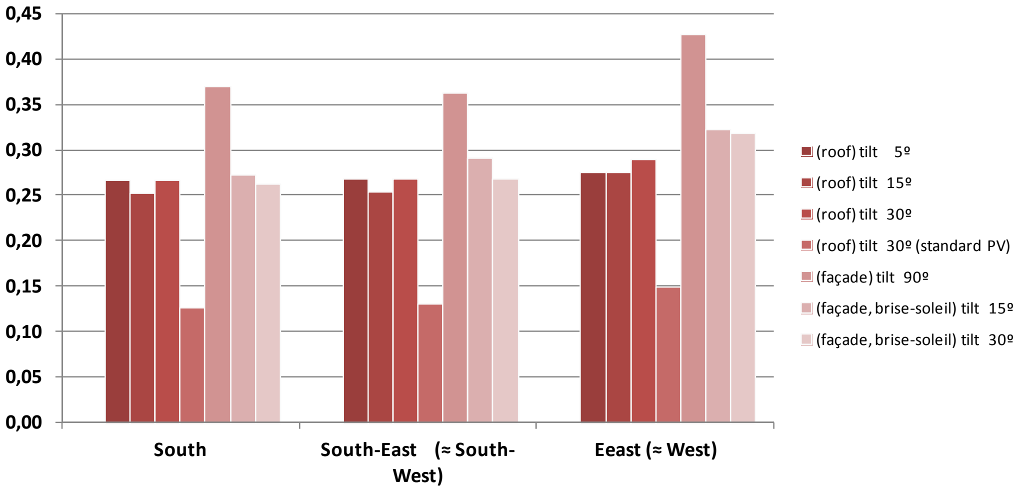
For PV technology: Crystalline semi-transparent (BIPV-1) **Location: Barcelona area (latitude 41º)**		**South**	**South-East (≈ South-West)**	**Eeast (≈ West)**
 	**(roof) tilt 5º**	1.157 kWh/KWp	1.147 kWh/kWp	1.116 kWh/kWp
	Cost per kWh	**0,266 €**	**0,268 €**	**0,275 €**
	(roof) tilt 15º	1.220 kWh/kWp	1.1192 kWh/kWp	1.106 kWh/kWp
	Cost per kWh	**0,252 €**	**0,253 €**	**0,275 €**
	(roof) tilt 30º	1.262 kWh/kWp	1.212 kWh/kWp	1.063 kWh/kWp
	Cost per kWh	**0,244 €**	**0,254 €**	**0,290 €**
	(standard PV)	1.262 kWh/kWp	1.212 kWh/kWp	1.063 kWh/kWp
	Cost per kWh	**0,138 €**	**0,144 €**	**0,164 €**
 				
	(façade) tilt 90º (c)	832 kWh/kWp	848 kWh/kWp	721 kWh/kWp
	Cost per kWh	**0,370 €**	**0,363 €**	**0,427 €**
 				
	(façade, brise-soleil) tilt 15º	1.129 kWh/kWp	1.056 kWh/kWp	955 kWh/kWp
	Cost per kWh	**0,273 €**	**0,291 €**	**0,322 €**
	(façade, brise-soleil) tilt 30º	1.177 kWh/kWp	1.152 kWh/kWp	970 kWh/kWp
	Cost per kWh	**0,262 €**	**0,267 €**	**0,317 €**

Source: the same as above

(c) It is the worst placement & positioning as far as *Annual Energy Performance* ratios, if tilt not beyond 30°



Energy production ratio (kWh/kWp) according different orientations and inclinations (tilt angle) in a BIPV-1 installation in the Barcelona area.



Average Annual €/kWh, according different orientations and inclinations (tilt angle) in a BIPV-1 installation in the Barcelona area.

3.2.3 Alternative Cost-per-kWh calculation as from LCOE formula :

As have been stated before (section 1.1.2), the usual LCOE (levelised costs of electricity) formula for comparison of cost-per-kwh for different technologies is:

$$\text{LCOE, €/kWh} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

where:

I_t = Investment (€) to be maid in year *t* ;(t= 1, 2, …n)

M_t = Operating and maintenance expenses (€) forecast for year *t*

F_t = Fuel expenses (€) forecast for year *t*

E_t = Electricity to be generated (kWh), in year *t*

n = Number of years of system operation (useful life)

r = discount (or interest) rate, %, divided by 100.

However, taking into account that 1) PV technologies do not consume fuel, 2) initial investment must be done before the system starts to produce (i.e., in 'year 0', not year '1'), and 3) that E_t may be made more precise, in terms of $\boldsymbol{E_t = P_t \cdot kWp}$ (where P_t is the *Electricity performance ratio* for the referred technology and system-positioning, for year *t of the productive period*), the above formula may befitted as:

[I]

$$\text{LCOE, €/kWh} = \frac{I_0 + \sum_{t=1}^{n} \dfrac{cI_t + M_t}{(1+r)^t}}{\sum_{t=1}^{n} \dfrac{P_t \cdot kWp}{(1+r)^t}}$$

where:

I_0 = Initial Investment (€) to be done in year '0'

cI_t = Complementary Investment (for inverters), to be maid each 10 years. I.e., in *t* = 11 and *t*= 21

kWp = power ('size') of the system

P_t = Performance ratio for year 't' = $P_1(1-d)^{t-1}$

d = Degradation rate

As has been underlined before (1.1.2) the basic feature of this alternative definition of the Cost-per-kWh is that it allows for introducing two refinements: 1) to take into account that P_t might show some yearly decreases because of a given degradation of the modules' performance (yield) along the productive years; for example, 1% yearly, which would mean $P_t=P_1(1-0{,}01)^{t-1}$; and 2) to allow for assuming that *operating and maintenance costs*, in real terms (i.e., apart from inflation), might vary along the years. Looking to it the other way round, if we would apply the LCOE formula assuming that yearly-changes in *M* and *P* will not be significant along the *n* years (or we have not enough reliable data for better alternative assumptions), and therefore we take them as constant values for each year, then the formula may be written as:

$$\text{LCOE, €/kWh} = \frac{I_0 + \sum_{t=1}^{n} \dfrac{cI_t}{(1+r)^t} + M \cdot \sum_{t=1}^{n} \dfrac{1}{(1+r)^t}}{P \cdot kWp \cdot \sum_{t=1}^{n} \dfrac{1}{(1+r)^t}}$$

Usual '*annual average*' calculation formula [II]

$$\text{€/kwh} = \frac{\left[I_0/n + cI/m + FC + M \right]}{P \cdot kWp}$$

where –as for a more intuitive reading of it- we can add that the repeated term $\sum_{t=1}^{n}$ $1/(1+r)^t$, for *n*=25 years and *r*=0, has a value of just 25, (= *n*); and for *r*=2/100, a value something lower, 19,52.

For comparative purposes, we have put above on the right the 'usual' annualised calculation formula we have used in the previous tables. As it can be seen, in the case of constant yearly values for *M* and *P* (as it is assumed in the usual annualised formula –on the right), both standard and LCOE formulas should return, for a given interest/discount rate, quite close values as cost-per-kWh: The standard formula takes into account 'r' as the *interest rate* –for calculating the financial costs of the system, FC- and the LCOE's taking it as the *discount rat*e.

In what follows we apply the LCOE formula to the same set of costs forecast and technical variables' values we have used when applying the 'usual' formula (the one on the right) in the previous tables, though introducing the refinement –in LCOE calculation- of *annual degradation rate (d) for the Performance ratio*. However, we keep taking for annual *operating an maintenance costs* a constant value of M=432 € -in real terms (apart from inflation)-, since we can not see from our market exploratory study any consistent reason for expecting significant changes, either upward or downward. Thus, specific LCOE calculation formula -which we apply in the next tyable- is:

LCOE cost-per-kWh =

$$\frac{I_0 + \sum_{t=1}^{n} \frac{cI_t}{(1+r)^t} + M \cdot \sum_{t=1}^{n} \frac{1}{(1+r)^t}}{kWp \cdot \sum_{t=1}^{n} \frac{P_1 (1-d)^{t-1}}{(1+r)^t}} \quad \rightarrow \quad \frac{I_0 + \sum_{t=1}^{n} \frac{cI_t}{(1+r)^t} + M \cdot \sum_{t=1}^{n} \frac{1}{(1+r)^t}}{P_1 \cdot kWp \cdot \sum_{t=1}^{n} \frac{(1-d)^{t-1}}{(1+r)^t}}$$

[Ia] [Ib]

As in the previous tables applying the usual annualised calculation, for the above LCOE calculation we take as interest/discount rate *r*=2%, under the reasoning argued before.

And regarding modules' *Performance ratio* degradation, according to our market research for technical data for the respective technologies, alternative values of *d*=0, =0,5% and =1% has been taken.

Since the following application of the above LCOE formula [Ib] is for comparative purposes, we have carried it out only for BIPV-1 technology (as well as for the standard PV one). And for facilitating the comparison of quantitative results (cost-per-kWh) we put also at the bottom of the table the cost-per-kWh resulting from the usual cost-calculation formula [II] we obtained in the respective previous tables.

As it can be seen –and could be expected, as argued before- for the specific case of *d*=0 the resulting cost-per-kWh (with an interest/discount rate of 2%) from LCOE formula and standard annual average formula are quite similar.

Cost per kWh -for BIPV technologies- applying LCOE formula

(taking the same costs forecast and performance estimates as for the previous tables)

			Technology BIPV-1		Standard Crys. modules Technology
	System size (power)		10	kWp	10
	Usueful operating life	n	25	years	25
	Operating life for inverters	m	10	years	10
	Initial investment (INV)		47.500	€	22.500
	(-) Cost of the offset building material (S)		7.180	€	-
(1)	Net Initial investmnent (INV-S)	I_0	40.320	€	22.500 €
	Compl. further Investment (replacement Inverters)	cI	3.500 €	in year 11	2.500 €
	“		3.500 €	in year 21	2.500 €
	Operating and maintenance expenses	M	432	€/year	432
	Annual Energy performance ratio, per kWp	P_1	1.262	kWh-year	1.262
	Degradation rate	d	0	%	0
	"		0,005	= 0,5%	0,005
	"		0,010	= 1%	0,010
	Interest/discount rate	r	0,02	= 2%	0,02
	Intermediate calculations:				
(2)	Present value (PV) of Complementary Investments, at r=2%		5.124	€	3.660
(3)	PV of Complementary Investments, at r=0%		7.000	€	5.000
(4)	PV of total Maintenance exp., at r=2%		8.434	€	8.434
(5)	PV of total Maintenance exp., at r=0%		10.800	€	10.800
(6)	"PV, at r=0%, of future kWh", with d=0		315.500	kWh	315.500
(7)	"PV, at r=0%, of future kWh", with d=1%		283.094	kWh	283.094
(8)	"PV, at r=2%, of future kWh", with d=0		246.386	kWh	246.386
(9)	"Present value, at r=2%, of future kWh", with d=0,5%		233.349	kWh	233.349
(10)	"Present value, at r=2%, of future kWh", with d=1%		221.079	kWh	221.079
	LCOE calculation:		€/kWh		
(11)	1): with d=0; r=2% → = [(1)+(2)+(4)]/(8)		0,219		0,140
	it is also equivalent to assuming some degradation but that the above P is an annual average for the *n* years				
(12)	2): with d=1%; r=2% → = [(1)+(2)+(4)]/(10)		0,244		0,156
	it implies to consider that the above P refers to the 1st. year, then degradates yearly				
(13)	3) with d= 0,5 % ; r=2% *d* → = [(1)+(2)+(4)]/(9)		0,231		0,148
	as for sensibility of LCOE to variable *'d'*				
(14)	4): with d=1%; r=0 → = [(1)+(3)+(5)]/(7)		0,205		
	as for sensibility of LCOE to variable *'r'*				
(15)	5): with d=0; r=0 → = [(1)+(3)+(5)]/(6)		0,184		
	as for sensibility of LCOE to d *and* r				
	Easing alternative calculations				
(18)	1^{st} and 3^{rd} ∑ term in the numerator, at *r*=2%, for t= 25		19,52		
(19)	∑ term in the denominator, with *d*=0,5%; *r*=2%		18,49		
(20)	“ , with *d*=1%; *r*=2%		17,53		
Standard annualised calculation (see previous tables)			€/kWh		
	With *d*=0 and r=2%		0,215		0,138

It merits to underline that, as can be seen, under the same starting assumptions (not relevant degradation ratio, and interest rate of 2%) the usual 'annualised' way of calculating the cost-per-kW (€/kWh) and the LCOE way give aproximately the same values.

4. OVERALL CONCLUSIONS AND REMARKS

These concluding remarks focuse on the respective summaries for the costs forecast for the non-conventional solar energy technologies our project is based on: Dish Sitrling (section 1.2), Solar-cooling fed by a Parabolic trough system (section 2.2), and the three kinds of non-standard thin layer photovoltaic elements (section 3.2).

First of all, the above respective data on the expected investment costs required for each type of system have been the base for then we being able to value different strategies regarding the set of specific innovative solar installations to be carried out within our Project, by each partner in the corresponding selected buildings. That should allow us to check that a given installations plan to be considered -regarding the specific type and size of solar-systems to carry out by each partner- be viable in budgetary terms.

More over, that cost-forecast for each different technologies, regarding the equipment to purchase and the installations services to contract, shuld be used for each partner as a basis for launching the respective public procurement process, and for then evaluating the corresponding offers.

These costs forecasts regarding initial investment required, maintenance costs, etc.,for each technology, together with the forecasts as far as their respective energy output (kWh), has also allowed us to elaborate a first approach to the comparative cost-per-kWh of these non-conventional technologies the project is devoted to.

Thus, regarding a scale-down Dish Stirling system, our first attemp for estimating the cost-per-kWh -for comparisson purposes (point 1.2.3) highlights the issue that best market-available models generate both electricity and termal energy, in an overall proportion of 25%-75% respectively. Therefore, cost-per-kWh should to be carried out considering in some way the use of both energy outputs. Under the technical assumptions regarding that issue made in section 1.2.4 (pages 38-39), we get in that first approach that the cost-per-kWh. would be between 0,24 € and 0,46 €.

It must be underlined here that these unit cost come out from a forecast for the total cost of a DS system's equipment obtained asking to possible providers the unit-price on the basis of purchasing just 1-2 units. Obviously, if we were talking of a higher market-demand for these DS systems –let us say, 2000 units per year- the corresponding economies of scale would allow manufacturers to be able to offer quite lower prices for the DS equipment.

Regarding a solar-cooling system fed by a PT solar filed, we should wait to the pilot installation be finished and evaluated as for having enough data for making a comparative unit-cost calculation as the above

As far as the three non-standard photovoltaic solutions –thin layer, in-building-integrated photovoltaic materials (BIPV)- considered in our project, the cost comparisson is at first more easy because both their output is only electric power and, more over, we have a very close alternative to compare with:

the standard PV crystaline modules. Our market costs study on these BIPV technologies has allowed to us to determine the following first estimates for their cost-per-kWh, assuming an installation of 10 kW of power (section 3.2.2; pages 96-98):

Using BIPV-1 (glass-laminated, crystalline semi-transparent (30-40%) technology, 0,24 €/kWh.

Using BIPV-2 (glass-laminated, crystalline thin-film (semitransparent: 10-20%), 0,201 €/kWh

Using BIPV-3 (thin-film, flexible; EFTE laminated), 0,18 €/kWh

These unit-costs estimates have then been compared here with the one calculated for an installation of the same power (10 kWp) based on the mature standard photovoltaic technology –which market prices per kWp installed, as it is very well known, have come falling drastically across last years; (we have taken "last moment" -2014- market price per module"):

Using standard PV crystalline modules (glass + tedlar laminated), 0,14 €/kWh.

which is a unit cost that allows certainly to confirm that this mass-produced technology has already reached the 'grid parity'.

However, for a proper comparison between the above cost-per-kWh, it should be taken into account at least two additional issues.

First, that any of the three BIPV technologies, different from the standard one- allows for a given saving in ordinary construction material. We have made a conservative estimate in that sense for the BIPV-1, and the result has been that the cost-per-kWh would come reduce from 0,24 € to 0,21.

And second, the scale of production. BIPV materials (modules, sheets, etc.) are yet produce at very low scales; specially compared with the case of the standard crystalline technology's modules. They are at present produced –mainly in China- at a scale of hundred of thousands of units. While the not yet comercially-developed modules for true building-integration substituing ordinary building materials are produced at a scale of sveral hundreds of units. So, it makes sense to ask ourselves a question parallel to what we have commented above regarding scale-down DS technology: which would it be the reduction in the purchasing costs of these BIPV equipment/elements if they were produced at a quite higher scale?

A question, economies of scale, we could extend to the cost estimated for a solar-cooling installation fed by a PT system, compararred to a conventional (electricity fed) cooling system.

And, of course, we should also introduce, for any cost-per-KWh comparison oriented to the 'grid parity' issue, the monetary value of the saving in CO2 emissions any of the solar technologies allows for.

However, we leave any further consideration on all these comparative-costs issues to be deal with in the project final reports, since tthen we will have got more precise, not forefast but real, information regarding both costs and yields, after having carried out and evaluated the different solar-systems installations.

As has been told, all the here presented costs-forecast and cost-per-kW calculations are a first attempt to the topic of calculating the estimated costs of the different solar systems we plan to carry out within the project. Further on, once the two pilot installations we are developing be evaluated –in terms of both costs and output, as well as the whole of the installations to be actually carried out by the respective partners, then we will be able to produce a more reliable study on comparative cost-per-kWh for the innovative solar technologies our project focuses on.

<last page>

General statement on the European Union

Project funded by the
EUROPEAN UNION

The European Union is made up of 27 Member States who have decided to gradually link together their know-how, resources and destinies. Together, during a period of enlargement of 50 years, they have built a zone of stability, democracy and sustainable development whilst maintaining cultural diversity, tolerance and individual freedoms. The European Union is committed to sharing its achievements and its values with countries and peoples beyond its borders.

بيان عام عن الاتحاد الأوروبي

يتكوّن الإتحاد الاوروبي من ال 27 الدول الأعضاء الذين قرروا معاً ربط خبراتهم والموارد ومصائرها. معاً، وخلال فترة 50 عاماً من التوسع، تم بناء منطقة من الإستقرار، الديمقراطية والتنمية المستدامة مع الحفاظ على التنوع الثقافي، التسامح والحريات الفردية. يلتزم الإتحاد الأوروبي في تقاسم إنجازاته وقيمه مع الدول والشعوب خارج حدوده.

General statement on the European Union (Greek)

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The 2007-2013 ENPI CBC Mediterranean Sea Basin Programme is a multilateral Cross-Border Cooperation initiative funded by the European Neighbourhood and Partnership Instrument (ENPI). The Programme objective is to promote the sustainable and harmonious cooperation process at the Mediterranean Basin level by dealing with the common challenges and enhancing its endogenous potential. It finances cooperation projects as a contribution to the economic, social, environmental and cultural development of the Mediterranean region. The following 14 countries participate in the Programme: Cyprus, Egypt, France, Greece, Israel, Italy, Jordan, Lebanon, Malta, Palestinian Authority, Portugal, Spain, Syria, Tunisia. The Joint Managing Authority (JMA) is the Autonomous Region of Sardinia (Italy). Official Programme languages are Arabic, English and French.

بيان حول البرنامج

هو برنامج للتعاون المشترك عبر الحدود لحوض البحر الأبيض المتوسط، هو جزء من سياسة الجوار والشراكة NPI CBC MedE 2007 – 2013إن برنامج
الأوروبية ومن آلياتها التمويلية. يهدف هذا البرنامج إلى تعزيز ودعم عملية التعاون المستدام والمنسجم على مستوى حوض البحر الأبيض المتوسط وذلك من خلال معالجة
التحديات المشتركة وتعزيز الإمكانات الذاتية. يموّل البرنامج مشاريع التعاون كمساهمة في التنمية الإقتصادية، الإجتماعية، البيئية والثقافية لمنطقة البحر الأبيض المتوسط.
قبرص، مصر، فرنسا، اليونان، إسرائيل، إيطاليا، الأردن، لبنان، مالطا، السلطة الفلسطينية، البرتغال، إسبانيا، إن الدول ال 14 التالية هي الدول المشاركة في البرنامج:
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